Assessment of Community Response to Odorous Emissions

R&D Technical Report P4-095/TR

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This project record describes the results of a study into assessment of the annoyance response resulting from exposure to odorous releases from industrial activities. The information in this document provides background information in support of the Agency Horizontal Guidance Note H4 (Odour) but should not be used in isolation from the guidance.

Keywords
Odour, annoyance, nuisance, dose-effect relationship, environmental impact assessment.

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EXECUTIVE SUMMARY

The purpose of this report is to provide the scientific background to assist in identifying defensible numerical limits for regulating exposure to odours in the UK, and identify further supporting research work as required to underpin such limits. The report is aimed at Environment Agency personnel and those interested parties that have a background in science and professional experience and expertise in managing environmental odour annoyance.

An introduction to the functionality of our sense of smell and its evolutionary development provides the background required to understand how we perceive odours, and the role of this sensory information in determining our behaviour. The relationship between perception, cognitive appraisal and behavioural responses such as odour annoyance is explored.

These general principles are then applied to the more pertinent question of how exposure to environmental stressors, such as noise and odour, can lead to annoyance and the cumulative effect of nuisance. A conceptual framework is developed and operational definitions are formulated for nuisance (long term effect of repeated annoyance), annoyance, annoyance potential (the relative propensity of an odour to cause annoyance), nuisance sensitivity (of a population) and nuisance potential (magnitude of potential annoyance associated with a source of odours).

A diagram of the complex process leading from production of odorants to odour nuisance is proposed. The main elements in this process can be identified as:

formation of odorants → transfer to atmosphere → atmospheric dispersion → exposure → population → perception → appraisal →annoyance →nuisance→complaints

To illustrate the concepts involved in characterising exposure to odour and its impact on humans, common features of concepts developed for the characterisation of noise are explored. The of ‘odour decibel’ or $\mathrm{dB}_{\mathrm{od}}$ is proposed as a useful unit, very similar to the use of the decibel in noise management. More advanced concepts to describe ‘loudness’ (phon) and ‘noisiness’ (noy) are discussed, to illustrate similar concepts that apply in odour (intensity and annoyance potential). As for noise, a regulatory practice of odours would require a straightforward, practical approach, not necessarily involving all theoretical concepts and refinements.

The methods to characterise odour exposure are then described in detail: detectability, including measurement of odour concentration and the notion of odour concentration, with its revised definitions from the European draft standard EN13725 ‘Air quality – Determination of odour concentration by dynamic olfactometry’. Other dimensions of odour and their measurement are then discussed in detail: intensity, odour quality (descriptive), hedonic tone and annoyance potential.

The methods to measure effects of odour exposure on community level are then outlined, including annoyance survey techniques and complaints analysis. The link between odours emitted at source and their community level effect is typically provided by dispersion models The characteristics and scope of application of dispersion models are discussed, including issues of particular relevance to odours, such as choice of meteorological data, choice of appropriate percentile values, choice of averaging time and the issue of applying peak-to-mean ratios.

After discussing the process and the tools that are available to attribute values and measure relevant parameters describing elements of that process, these elements are joined and integrated in a chapter that provides a detailed overview of epidemiological dose effect studies. Most of these studies have been carried out in the Netherlands and in Germany. The review of these studies shows that a strong correlation between calculated exposure to odours and surveyed percentages of odour-annoyed individuals in a population can be experimentally established. Correlation coefficients are typically $r > 0.9$.

An argument is presented that the exposure that is correlated to 10% of the population 'annoyed' as determined by survey is a level where a behavioural effect of odour exposure can be demonstrated in epidemiological dose-effect studies with high statistical confidence. This exposure level can serve as a starting point for setting limit and target values for regulatory use.

Results of fourteen surveys carried out around eleven different types of industrial sources in the Netherlands in the late 1980's and early 1990's are reviewed. These studies, involving a considerable total of 6276 surveyed individuals, show that for the combined dataset, 10% of the individuals in the test population are *seriously annoyed* by odour exposure at a calculated exposure of 5 $ou_E \cdot m^{-3}$ as a 98-percentile of 1-hourly averaged concentrations, calculated with a dispersion model. A short notation for that dose is $C_{98,\ 1\text{-hour}} = 5\ ou_E \cdot m^{-3}$. A recent review paper showed that the correlation between calculated exposure and surveyed annoyance is significantly better if the odour annoyance potential is taken into account in the exposure.

A recent large scale dose effect study, involving valid surveys of 2303 individuals, was carried out in 1999 to provide a more scientific underpinning for the policy on pig odours in the Netherlands. From the dose-effect study for pig odours described above, an indicative upper level of acceptable exposure can be derived for odours with relatively high odour annoyance.

The pig odour study provides clear and compelling evidence that at an exposure level of $C_{98,\ 1\text{-hour}} > 13\ ou_E \cdot m^{-3}$, even the most tolerant selection of the public, i.e. those with a direct economical stake in agriculture, show a measurable behavioural response in terms of percentage annoyance.

The most tolerant sample of the general public, residents of 'pig production concentration areas' with multiple sources for whom pig odours are a regular feature of their living environment, showed 10% annoyance associated with an exposure level of $C_{98,\ 1\text{-hour}} \approx 3.2\ ou_E \cdot m^{-3}$. This finding, combined with the reported overall result for a selection of a dozen (bio)-industry odours that 10% of respondents experience *serious annoyance* at exposure levels of $C_{98,\ 1\text{-hour}} \approx 5\ ou_E \cdot m^{-3}$, supports an upper limit for 'acceptable' odour exposure to odours with relatively high annoyance potential that should be no higher than $C_{98,\ 1\text{-hour}} \leq 3\ ou_E \cdot m^{-3}$.

For the general population exposure at $C_{98,\ 1\text{-hour}} \approx 1.3\ ou_E \cdot m^{-3}$ is associated with 10% annoyance, based on a substantial set of data with n = approx. 1500 respondents. This suggests a target value for odour exposure of $C_{98,\ 1\text{-hour}} \leq 1.5\ ou_E \cdot m^{-3}$ that would be appropriate to limit annoyance to a level where a behavioural effect can just be detected with high statistical confidence.

The data cited above are collected in the Netherlands. Ideally, dose-effect relationships for UK citizens in UK conditions should be assessed experimentally, to confirm the findings obtained abroad.

Considering the results of the available Dutch epidemiological studies it would appear that the exposure level of $C_{98,\ 1\text{-hour}} < 5\ ou_E \cdot m^{-3}$ that has been applied and accepted as a criterion for avoiding nuisance in the legal sense in a number of cases in the UK as first accepted in the planning procedure at Newbiggin-by-the-Sea (Department of the Environment, 1993) is evidently not erring on the side of caution (assuming that pig odours and wastewater treatment odours have similar odour annoyance potential).

The presented data and suggested limit and target values are valid for odours on the unpleasant end of the odour annoyance scale. In principle, using methods for assessing annoyance potential currently being developed, it is feasible to arrive at a form of differentiated criteria for odour exposure, depending on odour annoyance potential. This would lead to more lenient criteria for less unpleasant odours. Based on indicative data and practical experience in the Netherlands the correction factor for practical environmental odours will be less than a factor 10 in $C_{98,\ 1\text{-hour}}$ values for odours on the extremes of the annoyance potential scale, such as rendering on the high annoyance potential extreme and coffee roasting or bakeries on the low end of the scale.

In the final chapter the options for a conceptual framework for regulating odours are reviewed. The feasibility of constructing a deterministic model of all parameters contributing to odour annoyance and their interactions is reviewed, leading to the conclusion that attempts to construct such a model are typically too simplistic to be effective. A more pragmatic approach is favoured, in which exposure as calculated with dispersion models from emission measurements at source is correlated to annoyance levels in the population. This epidemiological approach regards the intermediate processes largely as a ‘black box’, but does relate the dose and effect with sufficiently high correlation to be effective.

The question: *Is the difference in odour annoyance potential of different odours relevant to their impact?* is discussed in detail, concluding that the differences in annoyance potential can be characterised, in a simple three-category system, using currently available information. A more evolved method to attribute a value to ‘annoyance potential’ is expected to become available in the near future (2002), and will enable more differentiation of exposure limits on the basis of quantified characteristics of each particular odour. There is no need to wait for this development, however, to include the concept of annoyance potential in a conceptual model.

Such a conceptual model for odour impact assessment is then proposed, as a starting point for designing a guideline. The model involves two stages of assessment:

- *A ‘hard’ quantitative assessment* through measurement of annoyance potential, odour concentration and volume flow, to characterise the emissions of odour in terms of annoyance potential. This parameter can be used in combination with dispersion modelling to describe and characterise exposure, and predict annoyance using epidemiological dose-effect data. This method would be an improvement over the current method using odour concentration and volume flow only. Instead of producing a measure for exposure to odour, a differentiation would be made to approximate the emission to malodour, as characterised by the annoyance potential.

- *A 'soft' quantitative correction* by using qualitative factors affecting the nuisance potential in combination with weighting factors, that can be adapted to the locality in question. In this manner, factors such as nuisance sensitivity of the exposed population and the context in which the exposure occurs can be taken into account. The magnitude of the influence of these factors and the quantitative nature of their inter-relationships is not substantiated in quantitative terms. That is why these terms must be applied and weighed on the basis of the judgement of the appropriate responsible authority, using consultation of those directly involved in the local situation as input. The conceptual model is not suitable to provide an established mechanism for quantifying the impact of these matters. It does, however, provide a structure to make judgments made on the local level transparent, and a method of incorporating these judgements in the overall quantitative odour impact assessment.

The model is presented graphically, giving an example of application as an illustration.

The report clearly indicates that the scientific data can only provide a starting point for the Environment Agency if it would consider defining a guideline level of 'acceptable annoyance'. The judgement on a suitable environmental quality objective for odours is ultimately a matter of policy as well as an issue of scientific investigation. This value can be lowered, creating a safety margin, or increased, indicating an acceptance that a certain level of annoyance and a real risk of nuisance is deemed acceptable.

What is acceptable or unacceptable as a level of annoyance is a matter policy and consensus on priorities and aspirations of a society. Scientific investigation can do no more than indicate a level where an effect is clearly detectable in the population.

The conclusions of the report provide a concise line following the course of the main argument contained in the report, and are therefore listed below:

1) The process leading from odour formation to annoyance to nuisance is complex, involving many parameters that influence the outcome: annoyance.
2) Cognitive appraisal and psychological coping strategy plays an important role in the determining whether nuisance will develop.
3) A full deterministic model of all factors affecting the occurrence of nuisance is not within reach as yet. We therefore have to regard the most important factors relating cause and effect, and find relevant correlations in a pragmatic, empirical model.
4) Therefore, air quality limits must be formulated on the basis of epidemiological studies describing the relationship between dose and effect.
5) Odour exposure can be characterised using measurement at source combined with dispersion modelling. Methods for characterising odour exposure are reasonably well established:
    a) Standardised methods for measuring odour concentration and emission rates are well established, and their intrinsic uncertainty is known.
    b) Methods to refine odour emission measurement by adding a correction factor are available (intensity, hedonic tone). An overall method to characterise annoyance potential is currently being developed, expected to become available at the end of 2001.

    c) A classification for annoyance potential can be made available relatively quickly using simple survey based ranking.
    d) Dispersion models have considerable limitations, but can be used to characterise odour exposure in terms of probability of exposure over a certain hourly concentration over long periods of time (3-5 years).
6) The effect in terms of changes in behaviour indicating annoyance caused by odour exposure can be detected using questionnaire survey techniques.
7) The relationship between calculated odour exposure and percentage of people annoyed as measured by survey in a population is strong and has been experimentally confirmed in well over a dozen studies in the Netherlands and Germany.
8) A level of 10% of the population annoyed can be clearly and reliably detected, with good statistical confidence that the measured effect is not the result of methodological error.
9) Therefore an annoyance level of 10% measured by survey is a good indicator that odour exposure causes a behavioural effect.
10) An odour exposure level associated with a just measurable behavioural effect is a good scientific starting point for setting air quality criteria for odour exposure. The actual levels of such criteria need to be set as a matter of policy, taking into account the priorities and aspirations of a particular society at a particular stage in its history.
11) Available epidemiological data suggest that a behavioural effect of 10% annoyance is associated with odour exposure of $C_{98,\ 1\text{-hour}} = 1.5\ ou_E \cdot m^{-3}$ for an odour with relatively high annoyance potential. This exposure level is indicative for measurable odour annoyance in the general public, for an odour with a relatively high annoyance potential (pig production odour). It can be used as a starting point for determining a target value for managing exposure to environmental odours.
12) For a population accustomed to exposure from that odour, from a multitude of sources in the residential environment, an exposure of $C_{98,\ 1\text{-hour}} = 3\ ou_E \cdot m^{-3}$ to an odour with relatively high annoyance potential is associated with a clearly measurable behavioural effect as a result of odour exposure. This value can be considered as a starting point for setting a limit value for managing exposure to environmental odours.
13) For a specifically tolerant sample of the population, of those directly involved in the business producing the odours, a clearly measurable behavioural effect of 10% annoyance is associated with an exposure to $C_{98,\ 1\text{-hour}} = 13\ ou_E \cdot m^{-3}$. In separate studies for a dozen agricultural and industrial odours an effect of 10% of the exposed population experiencing '*serious annoyance'* was demonstrated to be associated with an exposure of $C_{98,\ 1\text{-hour}} = 5\ ou_E \cdot m^{-3}$. This would indicate that an upper limit to acceptable exposure to odours with high annoyance potential to lie in the range of $5\ ou_E \cdot m^{-3} < C_{98,\ 1\text{-hour}} < 13\ ou_E \cdot m^{-3}$
14) A correction factor to differentiate air quality criteria for odours with high, medium or low annoyance potential is justified. The effect of such a factor is not expected to be more than a factor 5 to (at most) 10 as expressed in $C_{98,\ 1\text{-hour}}$ concentration levels in $ou_E \cdot m^{-3}$.
15) Setting limit and target values for odour exposure for regulatory use is a matter of policy. Science can provide an exposure level associated with a behavioural annoyance effect that can just be detected, with high statistical significance. An exposure level associated with acceptable annoyance should reflect the priorities and aspirations of society. To determine a level that reflects consensus is a matter of policy.
16) As the notion of 'acceptable annoyance level' may change with time, regular reviews of policy are required, taking into account perceived effectiveness of policy and updated epidemiological information.

17) Exposure levels currently associated in the UK with the legal objective of avoiding nuisance, such as $C_{98,\ 1\text{-hour}} < 5\ ou_E \cdot m^{-3}$ appear to be relatively lenient relative to the results of dose effect studies in other Northern European countries.
18) Epidemiological dose effect data relationship odour exposure and annoyance for UK conditions would be very welcome as a starting point for setting environmental quality objectives for odour exposure.

The report has two annexes providing background information for reference:

- Annex A: Overview of odour policy development in other countries.
- Annex B: Overview of relevant legislation with regard to control of odour releases and odour nuisance in the UK.

Recommendations are made identifying research that would contribute to arriving at a suitable guideline for application in the United Kingdom:
The crucial elements would be:

1. Confirmation of dose-effect relationships for the UK situation.
2. Identification of a standard set of quantitative risk factors, and the direction and (maximum) weighting factor for application within the conceptual model.
3. Comparison of the results for with existing studies abroad for similar odours can yield useful additional information on relative odour annoyance from different source.
4. Establishing a rank order for annoyance potential, based on UK data. Such data can be established by interviewing Environmental Health Officers with odour experience, or by comparative testing in laboratory conditions.
5. Setting limit and target values for odour exposure associated with levels of annoyance that are considered acceptable, on the basis of the outcome of research as described in the previous points.
6. Establish levels of equivalent annoyance for odours with different annoyance potential.

At a later stage improvements could be introduced by:

1. Introduction and validation of a standard method for quantitative measurement of odour annoyance, that is currently being developed in the Netherlands.
2. Research into factors that can contribute to characterising nuisance sensitivity in a particular population.
3. Research aimed at improving exposure characterisation by using improved short term models or peak to mean estimates by application and validation in dose-effect studies as mentioned above.

CONTENTS

1 INTRODUCTION

1.1 Scope and purpose

The purpose of this report is to provide the scientific background to assist in identifying defensible numerical limits for regulating exposure to odours in the UK, and identify further supporting research work as required to underpin such limits.

The report is aimed at Environment Agency personnel and those interested parties that have a background in science and professional experience and expertise in managing environmental odour annoyance.

The core of the study will be formed by existing scientific data that are available in the form of epidemiological dose-response studies, where the annoyance response of a population exposed to given levels of odours has been assessed.

This study aims to deliver a well-documented overview of the scientific background and reflecting the current state-of-the art relating to characterisation and management of environmental odours and their impact on people.

The feasibility of using existing scientific information and practical regulatory experience to develop a consistent framework for management of odour impacts for practical application in determining licence applications will be assessed. The report identifies the actions that are required to arrive at such a framework, before it can be implemented as a guideline.

1.2 Objectives

This report aims to provide the necessary scientific background data for the purpose of

- Assisting in identifying defensible numerical target and limit values for odorous emissions or, if such data are not sufficiently available, demonstrating that setting such limit and target values requires further supporting research work.
- Providing a robust underpinning for the line taken

The report aims to familiarise the reader to the concepts and processes of odour perception and appraisal and the methods used for assessment of relevant attributes. To substantiate a quantitative approach to managing annoyance caused by environmental odours released from agricultural and industrial activities, the report focuses on studies describing the relationship between exposure to environmental odours and the undesirable effects that such exposure may cause, in terms of annoyance and nuisance.

The experiences of other countries are reviewed in Annex A in order to provide an international perspective on the issue. Regulatory and management approaches as applied or proposed in other countries are reviewed, and an overview of current regulatory approach in the UK is provided in Annex B.

The report provides links between the scientific data relating dose and effect and the concepts, methods and techniques that can be used for the day-to-day practice of odour assessment for regulatory applications.

A conceptual framework for odour impact assessment in the licensing process is tentatively proposed as a starting point for establishing guidance on odour annoyance prevention and odour impact assessment.

2. ODOUR PERCEPTION AND APPRAISAL

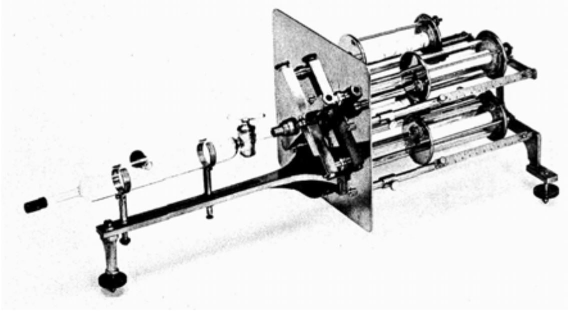
This chapter presents a brief introduction to the history of research relating to smell, and the relevance of smell as a factor determining our behaviour. It explains the evolutionary relevance of the sense of smell, and touches on the relevance of smell related genes in the human genome. The anatomy and physiology of our sense of smell are introduced. The relationship between sensory perception and cognitive processes and the behavioural responses that follow is introduced. Factors that contribute to variations in response between individuals and populations are presented. The chapter covers a wide area of research and aims to provide no more than a brief overview that will help the reader to understand the underlying sensory processes that contribute to environmental impact. References for further reading are provided.

2.1 The functionality of our sense of smell and its evolutionary development

Humans, as all creatures, rely on their senses to obtain information to assess their environment. All sensory perception, after conversion to impulses in our nervous system, is ultimately provided to the brain for appraisal and is used to direct our behaviour is such a way as to optimise survival.

The sense of smell, like the senses of sight and hearing, is a tele-sensor, in that it provides information from the environment with a relatively large spatial reach. This is in contrast to the contact senses (taste, equilibrium, touch, temperature, pain) that monitor events in or directly around the body.

The evolutionary function of our sense of smell is the same as for other species: it provides vital information that helps us to evaluate our environment. In simple terms of behaviour, perception of odours can trigger two basic behavioural responses: *avoidance* or *approach.* These basic responses can occur for example in the context of judging food or water or air, but also in a social or sexual context. It is now estimated that there are between 500-1000 odorant receptor genes in both humans and mice. This number of genes, specific to the olfactory system, comprises 1.5-3% of the approx. 30,000 genes that make up the human genome. This number is second only to the receptors of the immune system. The relatively large amount of genetic information devoted to smell perhaps reflects the evolutionary significance of this sensory system for the survival and reproduction of most mammalian species (Axel, 1995).



The molecular and physiological processes that enable humans to detect and identify thousands of odours, detecting some molecules at concentrations as low as a few parts per trillion, are only just being unravelled in recent research. This does not imply that the study of our sense of smell is a new science. The first measurement of an odour threshold was reported more than a century ago (Fischer and Penzoldt, 1886) and a dedicated instrument for olfactometry (above) was developed, named 'olfactometer', and used in academic research the 19th century by Hendrick Zwaardemaker Czn. (Haarlem, 1857 – Utrecht, 1930). A detailed introduction to smell physiology, and much more, is provided in the Handbook of Olfaction and Gustation (Doty, 1995). A brief outline of the physiology of olfaction, as far as it is relevant to the scope of this report, is provided in section 2.2.1.

In essence, the function of our smell sensor is similar to that of all senses: to translate environmental information into nerve signals transmitted by neurons firing in our brain. This information is then evaluated in the brain. This process is broadly termed appraisal. The outcome of this appraisal can modulate the behaviour of the individual.

Human perception of the environment through vision, hearing, touch, smell and taste is characterised by a good discrimination of stimulus intensity differences and a decaying sensitivity to a continuous stimulus (Berglund, Lindvall, 1995).

2.2 How do we perceive odours?

We perceive odours in the air we breathe with our sense of smell, which forms part of the human ability for chemoreception (smell and taste). Sniffing increases airflow and turbulence, which enhances the interaction with the actual sensor cells, at the top of the nasal cavity. The sensor cells are actually a direct extension of the brain, through a perforated bone plate. A layer of mucus covers the sensor cells. Compounds are dissolved into the mucus and can then interact with the sensor cells. The signals are transferred to the brain by the first cranial nerve (CN I).

The olfactory sense is not the only way to detect chemicals in air. There is a second neural pathway, via the fifth cranial nerve (CN V), the trigeminus nerve that can be excited by free nerve endings in the lining of the nose itself. These nerve ends detect chemical irritation and produce sensations such as irritation, tickling, burning, warming, cooling and stinging.

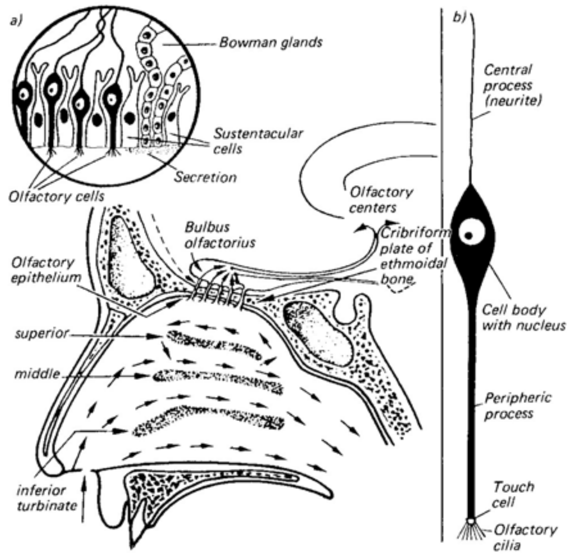
Many odorants stimulate both sensory systems (Cain and Murphy, 1980). However, although trigeminal perception indicates that ‘something is in the air’, it does not provide information on the character of the odour. The ability to identify odorants and describe them is the unique and remarkable faculty of our sense of smell.

2.1.1 Anatomy and physiology of the human olfactory sense

A brief summary of the anatomy and physiology of our sense of smell is presented. A detailed understanding of this section is not required as the focus of this report is on the environmental impact and appraisal of the smell, not the narrow issue of how the stimulus is sensed and converted into nerve signals. For further reading: Handbook of Olfaction and Gustation, Doty (ed.), 1995.

The **olfactory region** of the nasal mucosa covers the narrow flat roofs of the clefts as well as the upper part of the superior turbinates, in the nose cavity. The sensitive region, comprising a total area of about 4 cm^2, contains about 10 to 30 million receptor cells, which terminate in a knob with about ten cilia forming a network in the covering mucosa as shown in Figure 1.

Figure 1 The anatomy of the human nose. From: VDI 3881:1986 Blatt 1 Olfaktometrie



The anatomy of the human nose
a) Sagittal cut through the nose
b) Single olfactory cell in strong magnification
Modified illustration according to *A.B. McNaught* and *R. Callander* [22] and *K.-H. Plattig* [23]

It is generally assumed that olfactory receptor sites are on the ciliary surface membrane. Odorant stimuli bind to a protein receptor site in the membrane. The stimulus-activated receptor activates G-proteins, which evoke an enzyme cascade, see Figure 2. At the end channel proteins are phosphorylated that may affect gating of ion channels. Until now *no* specific receptors have been found. It is assumed that about 100 to 300 receptor classes exist and each cell is more and less sensitive to each odorant and therefore a great variety of combinations are possible. It is said that the human being can differentiate about 10.000 odours with differing qualities. To date it is not possible to predict an odour sensation from the chemical structure of an odorant or to establish an odorant classification system on that basis. Some odorants with almost identical structure may elicit quite differing odour descriptors. In some cases, the character of the smell can change drastically, depending on concentration of the odorant.

The axons of receptor cells form bundles, called olfactory nerve filament fibres. This arrangement allows the synchronous excitation of a number of cells, which are not close neighbours. This enhances stimuli of lower intensity. Lateral inhibition processes at subsequent cell layers suppress intense and long lasting signals. This phenomenon is called *peripheral adaptation*, which protects humans from stimulus overflow.

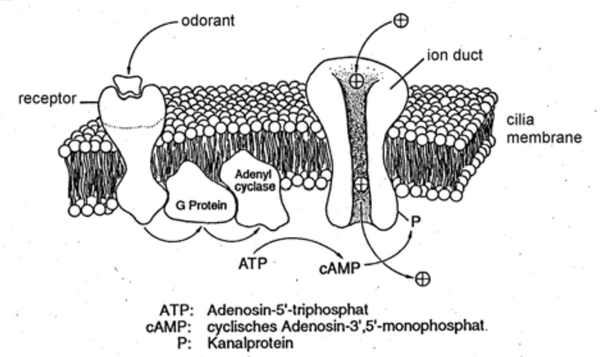


Figure 2 Model of olfactory membrane and transmission of signals. Modified from Plattig, H.H.,1995

The filaments enter the olfactory bulbs where they synapse with the dendrites of mitral and tufted cells. Several hundreds of primary olfactory axons converge on a single mitral cell. The information is already processed here. From the bulbus olfactorius the second and third order neurones pass by the limbic system and the thalamus to the projection area of the brain. In higher olfactory centres the nervous signals are linked to signals from other sensory input information and the odour perception including an effective interpretation relative to sensory events in memory is done mainly in the cortex. This process of cognitive appraisal may lead to negative attribution of the stimulus, after being moderated by the environmental context. If that negative attribution leads to some form of coping behaviour, we speak of annoyance.

2.2.2 Processing of olfactory information in the brain: appraisal

Appraisal is a complex process, involving various parts of the brain. The sense of smell differs from other senses, because the olfactory information goes straight to the limbic system – a fast route to the brain's emotional centre. Unlike all other senses the nerves do not cross over from sensor to the opposite half of the brain. The hippocampus and the attached amygdala initially process the information and also reflect the information to a part of the cortex directly below the frontal lobes. Whether we find a smell pleasant or unpleasant depends crucially on what memories are associated with it. There is experimental evidence that the memory for smells starts to be formed even before we are born, affected by the diet of the mother (Doty, 1995). A particular smell may have positive connotations for one individual and negative connotations for another. Scanning studies suggest that pleasant odours activate the frontal lobes' smell area, particularly on the right hand side. Unpleasant odours activate the amygdala and the cortex in the temporal lobe (insula). The direct connection to the limbic system, the brain's emotional and memory organisation centre, gives smell its power to elicit strong emotional memories (Carter, 1998, and Plattig, 1995).

Since the sense of smell can detect and recognise many chemicals at concentrations far below those that would cause direct physical effects, it stands to reason that detection of such substances may cause anxiety and affect well-being at lower levels than those established on toxicological or physiological effects.

However, our sense of smell does not always provide good guidance on the risk of exposure. Humans are very sensitive to certain repulsive-smelling compounds, such as those produced in trace amounts by some bacteria and moulds, e.g. methyl mercaptan and trimethylamine. Heightened odour sensitivity to these compounds may have developed in evolution to provide protection against dangerous infections or food poisoning (Amoore and Hautala, 1983).

In general, however, there is no clear correlation between odorous and toxic properties of chemicals. Some compounds cannot be detected by smell, even when they are present in toxic concentrations. A prominent representative of such compounds is carbon monoxide, which is odourless yet potentially deadly. Other compounds, like the ones mentioned above, trigger a response as a result of their odorous properties, although they are present in concentrations well below toxic levels. These can cause anxiety well before acute toxic effects occur.

Odour detection by humans takes place within seconds or minutes, followed by a dynamic interplay of appraisal and coping. Awareness of exposure can cause anxiety (Schiffman, 2000), which is manifested by somatic symptoms of excessive autonomic arousal (such as dyspnoea, palpitations, sweating, tremulousness, dry mouth, diarrhoea, or hot and cold flashes) and increased motor tension. Other symptoms include chest pain, dizziness, faintness, and paresthesias. Hyperventilation may be a response to anxiety and may also lead to many of these symptoms. Although these symptoms are normal physiologic responses to life-threatening situations and frightening occurrences, they might lead to avoidance behaviour (e.g. closing windows, contacting plant operators, environmental agencies and health authorities to register complaints).

2.3 The relationship between perception, appraisal and odour annoyance

Odour annoyance occurs when a person exposed to an odour perceives it as unwanted or objectionable. Major factors relevant to perceived odour annoyance are:

- Offensiveness of the odour,
- Duration of exposure to the odour,
- Frequency of the odour occurrence,
- Tolerance and expectation of the exposed subjects.

Exposure to odours that are perceived to be unpleasant can affect well-being at levels of exposure well below those that would lead to physiological or pathological effects, e.g. sleep disorders, headaches, respiratory problems. We use our sense of smell to assess our environment, our food, and our companions. A smell that is perceived to be unpleasant in the context of our personal environment is hard to ignore, and easily leads to an overall negative appraisal of that environment itself. The most simple behavioural response is 'fight or flight', in other words to move away from the source of the stimulus that caused the negative appraisal. In our modern crowded world, the options to flee are limited, especially when the exposure occurs in our home. If exposure to smells with negative appraisal occurs repeatedly, it can affect our well being, and cause stress related symptoms. When this occurs, exposure to odours becomes an issue of public health.

A comprehensive study of the physiological, psychological and sociological mechanisms that contribute to their incidence of odour-induced annoyance is presented in the dissertation of Cavalini (1992). The most relevant points are summarised here.

Exposure to perceivable odours causing a negative appraisal is considered an 'ambient stressor'. When an individual perceives and appraises an ambient stressor that will call for some form of coping behaviour. In the interaction between the individual and his or her environment two mental processes can be identified. Once sensory perception has occurred, the information is processed in the brain to decide its relevance. The brain relates the current information to information in memory, e.g. memories about previous experiences with that smell and the current behavioural context. Odour detection and appraisal is a process that takes place in matter of seconds or minutes. The result of this process of cognitive appraisal is a decision on the significance of the perception and the magnitude of stress that may result from this transaction between the individual and his/her environment. Appraisal is followed by a second process of *coping* in which the individual adapts to the situation that was appraised as potentially stressful by cognitive actions and behaviour. During exposure, a dynamic interplay of appraisal and coping takes place.

Two main types of coping strategy are identified:

- *Problem focussed coping* leads to attempts to control the problem by developing active behaviour aimed at removing the cause of stress, e.g. closing windows, calling authorities or operators to complain, keep diaries and submit complaints etc.
- *Emotion focussed coping* is not aimed at changing the environment by removing the unpleasant stimulus, but consists of modulating the emotional response that is the result of the appraisal, e.g. denial, 'Zen', seeking distractions etc.

Ambient stressors such as noise, perceptible air pollution (particulates and irritants), artificial light and smells have a number of attributes in common. They can be perceived, they are seen as a negative factor compromising quality of life, their impact is chronic, and their effects are generally not considered to have direct urgency.

The relationship between exposure to physical or chemical parameters, such noise or odours, and subjective responses, such as annoyance, are typically not easily demonstrated and quantified (Berglund, Lindvall, 1995). The difficulty lies in the complexity of assessing the dose of exposure, for individuals and in the large variation in subjective responses and their expression that may be related to that exposure. In research, this often implies that a large proportion of variation cannot be attributed to the relationship between dose and effect as measured. This is not so surprising, considering the complexity of both characterising dose in time and space and the variety and complexity of sensory, cognitive and behavioural aspects that determine the outcome of effect in terms of ‘annoyance’.

Cavalini (1992) describes efforts to improve the characterisation of exposure. He used various atmospheric dispersion models (short and long term models) and studied both continuous and intermittent sources (e.g. sugar beet processing). He found that attempts to use short term models, in an attempt to characterise ‘real time’ exposure episodes over relatively short periods, did not provide a better estimate of annoyance than the use of multi-year long term models. He concluded: *'The effects of exposure to intermittent episodes of strong odours are similar to the effects of exposure to permanent moderate odour'.* Winneke (1998) later observed that in a situation where the source of an odour had been abated three years before the dose effect survey, the proportion of individuals annoyed by odours in the subpopulation of those who had lived in the area less than three years was significantly less than the proportion of individuals annoyed that had lived in the area more than three years. These observations lead to the following conclusions:

- Nuisance is not caused by short-term exposure, and is not alleviated by relatively short periods (months) of absence of the ambient stressor. Nuisance appears to be caused by long-term intermittent exposure to odours.
- The association between a particular source of odour and annoyance in the mind of an individual with a history of annoyance due to that source is strong and long lasting. This association can persist for years and may cause annoyance at lower exposure levels than would be the case for individuals with no exposure history for that ambient stressor.
- Annoyance in an individual is apparently determined by a cumulative perceptual and appraisal history over longer periods of time, or even a lifetime. Memorable episodes or ‘peaks’, where appraisal was most negative as a result of exposure to high intensity and unfavourable behavioural context appear to determine the interpretation of this history in memory.

Cavalini (1992) tried to achieve a better prediction of annoyance levels by improving the characterisation of the exposed individuals, defining a number of parameters that could be indicative for ‘nuisance sensitivity’.

A number of ‘predictors’ for annoyance sensitivity were identified by Cavalini (1992) and he formulated hypotheses that could be tested in his data by statistical analysis of variance of survey data of an exposed population to test for statistical significance of the proposed relations. These data were collected in direct interviews. The following predictors were tested, at similar or equal exposure levels, with the outcome as described below:

- **Perceived health status.**
  Hypothesis: *individuals with health complaints have a higher probability of experiencing annoyance than those with fewer complaints, at the same exposure level.*

This hypothesis was confirmed by Cavalini's work, and later by other researchers (Steinheider, 1993). Higher exposure to odours in itself did not relate to the prevalence of health complaints, the link was the occurrence of annoyance.

- **Anxiety**
  Hypothesis: *Individuals who feel anxiety that odour is related to health risks have a higher probability to experience odour-induced annoyance.* Cavalini's data confirmed this hypothesis.
- **Coping strategy**
  Hypothesis: *Individuals with the propensity of* ***problem-focussed coping*** *are more likely to experience odour annoyance than those with a propensity for* ***emotion-focussed coping***. The data Cavalini (1992) analysed showed a weak but significant correlation. Other researchers found a firmer significance for this link (van der Linden, 1989).
- **Economic dependence**
  Hypothesis: *Individuals with an economic interest in the activity associated with the source of odour are less likely to experience annoyance than others.* This hypothesis was clearly confirmed to be significant by Bongers (2001A)
- **Personality**
  Hypothesis: *Individuals who believe to be the focus of control over their environment are more likely to experience annoyance.*Only a weakly significant link was found in support of this hypothesis (Cavalini, 1992)
- **Age**
  The relationship between age and the probability to experience odour-induced annoyance was clearly significant (Cavalini, 1992 and Amoore, 1985)
- **Residential satisfaction**
  Hypothesis: *The more satisfied an individual indicates to be with the residential situation; the lower the probability of experiencing odour induced annoyance.* This hypothesis was confirmed with a significant correlation in the data (Cavalini, 1992)

Steinheider (1993) presented data supporting the link for coping strategy, age and perceived health. Winneke demonstrated an additional factor.

- **History of exposure and annoyance**

A history of an individual in terms of odour-induced annoyance was demonstrated to cause a long term heightened annoyance sensitivity, even three years after the high exposure was abated (Winneke, 1998).

See section 0 for a more summary of factors that can contribute to variations in annoyance sensitivity in individuals.

In addition to individual traits, the appraisal of smells can also be significantly modulated by the context of exposure, and the information provided to the individual. This influence of cognitive factors on odour appraisal can be illustrated by an experiment where 90 adults were divided into three groups, each of which was given different information about chemicals to which they would be exposed (Dalton E.A., 1997). Researchers told the neutral group that the chemical they were to be exposed to, is approved for, and commonly used in olfactory research. The positive bias group was told that the odour was from natural extracts that are used in aromatherapy and that it is reported to have beneficial effects on mood and health. The negative bias group was told that the chemical was an industrial solvent that is reported to cause adverse health effects and cognitive problems following long-term exposure.

Following the exposure, the subjects completed questionnaires to collect information on health symptoms. The positively biased group reported far fewer symptoms than the other two groups. Neutrally biased subjects responded similar to the negatively biased group. One interpretation for this finding may be that a normative response exists to many odours, particularly odours that are not common to the environment, or not clearly known to belong to the 'odour landscape' of living environment, is negative.

The human response to odours, and particularly the responses that are relevant to well being and hence to public health, are largely determined by psychological, cognitive processes. We smell with our nose, but the appraisal and the coping behaviour it generates has its locus between the ears.

2.4 The variation in odour perception between individuals in a population

2.4.1 Inter-individual variation of sensory perception

Olfactory acuity (the ability to smell a certain odour) in the population follows a lognormal distribution. Two percent of the population are predictably hypersensitive, and two percent insensitive.
The insensitive range includes people who are anosmic (unable to smell) and hyposmic (partially unable to smell). A person may be hyposmic to one odorant and hyperosmic to another.

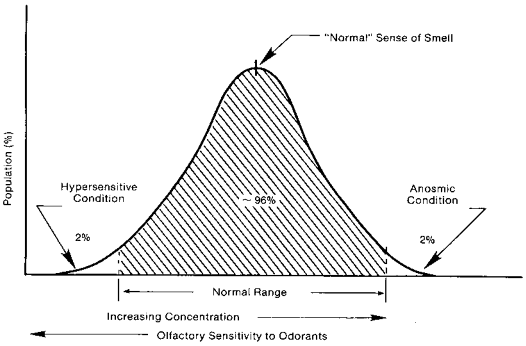


Figure 3 Diagram representing a frequency distribution of olfactory sensitivity

The standard deviation in the distribution of individual odour thresholds is approximately the same for all odorants so far tested, averaging very close to a factor of 4 (Amoore, 1985). Accordingly, for a certain odorant, 68% of persons tested are expected to have individual thresholds within a sixteen-fold range of one-quarter of the median, and four times the median.

Factor	Relative threshold
Average woman	0.8
18 yr. Male	0.5
62 yr. Male	2
Smoking during test	4
Chewing during test	4
Head cold	4
Nasal allergy	4
Undirected test	4

Table 1 Odour perception threshold compared to that of an 'average' healthy forty year old male (=1.0). Source: Amoore, 1985)

Olfactory responses of individuals vary with age. Increasing age is correlated with decreasing acuity in odour perception. Female assessors on average demonstrate a slightly lower odour detection threshold than male assessors from the same age group. Factors such as health status (e.g. cold, nasal allergy), smoking behaviour, personality, educational background and training may contribute in some degree to the ability to assess an odour.

Various factors influence odour detection thresholds, as is illustrated in Table . The magnitude of the influence is shown as the ratio of the threshold in a subgroup and the threshold of an average healthy forty year-old male (source: Amoore, 1985).

Subjects in good health can normally reproduce their individual odour thresholds for a certain compound within a factor of 2. Accordingly, 95% of test results of an individual's threshold for a certain compound should fall within a four-fold range of one half, and two times the median. (Van Harreveld, 1995 and EN13725, 1999).

There is a substantial difference however, between the level of odorant that *can* be detected, and the level that *will* be detected. In a study on the influence of various degrees of distraction on the responsiveness of people to well-known warning odours, substantial differences were found between directed and undirected tests. In a ***directed*** test, the attention of the subject is purposely focused on the sole objective of detecting odour. In the ***undirected*** test, the subjects were given no indication of the object of the exercise. Re-calculation of the data on log/probit coordinates resulted in a four-fold raised detection threshold for the undirected test as compared to the directed test (Amoore, 1985). Although the authors know no supporting data, the hypothesis that this factor contributes to the apparently heightened sensitivity of 'chronic complainants' seems plausible.

Three compounds (ethylmercaptan, phenyl ether and isoamyl acetate) were tested for their capability to wake a *sleeping person* (Fieldner, 1931). The odorants can be regarded as more or less purely olfactory stimulants, i.e. they cause little or no irritation through stimulation of the trigeminal nerve. An odorant concentration of about 20,000 times the detection threshold was required to awaken 50% of soundly sleeping persons (Fieldner E.A., 1931).

2.4.2 Intra-individual variation: nuisance sensitivity

Characterising individuals or populations to distinguish differences in nuisance sensitivity is no easy task. A wide range of factors affect human behaviour, and predicting the variations in response to unpleasant odours is therefore likely to be a complicated issue, where many variables are involved.

The following factors are associated with nuisance sensitivity:

- **Perceived health status** – worse health, higher sensitivity
- **Anxiety** – more concerns about health risks, higher sensitivity
- **Coping strategy** – problem focussed coping strategy is linked to higher sensitivity than emotion focussed coping
- **Economic dependence** – economic dependence leads to lower sensitivity
- **Personality** – those who believe to be the focus of control have higher sensitivity
- **Age** –annoyance sensitivity decreases with age
- **Residential satisfaction** – those more satisfied are have a lower sensitivity
- **History of exposure and annoyance** – a history of odour induced annoyance is associated with higher sensitivity

Although these correlations have been demonstrated (see section 0), there is currently no operational method available to characterise a population in terms of a quantitative 'annoyance sensitivity index' that would be suitable for application in odour policy implementation.

In the absence of an accepted quantitative expression of ‘nuisance sensitivity’, a quantitative frequency distribution representing inter-individual variation in a population is not available. To estimate the magnitude of the effect, however, it can be stated that the effect of these factors will contribute to reduce a tolerance level to an odour from a certain ‘acceptable level of intensity’ in a less sensitive or sensitised individual to the recognition threshold. In a person with maximum nuisance sensitivity, negative appraisal will be triggered, after all, as soon as the odour can be identified.

3. OVERVIEW OF METHODS FOR CHARACTERISING ODOROUS AIR

This chapter introduces the factors involved in characterising odours. It defines the four major characteristics of odours of relevance to the sensory perception and the respective approaches for determination of these attributes for specific odours. In addition, a fifth attribute recently proposed to characterise odour in terms of its propensity to cause odour annoyance, termed "annoyance potential" is introduced.

3.1 Characterising odours: psychophysical dimensions of odour perception

Measurement of the stimulus-response characteristics of odorants constitutes a branch of science known as psychophysics. The sensory perception of odorants can be characterised by four major attributes or dimensions:

- detectability;
- intensity;
- hedonic tone;
- odour quality;

A fifth attribute has been proposed recently [van Harreveld, 1999] to characterise the propensity of an odour to cause odour annoyance. This attribute is currently the subject of research. However, no operational method for characterisation and interpretation is currently available for this fifth attribute:

- annoyance potential.

These attributes and the existing methods to characterise them through measurement are described in more detail in the sections below.

3.1.1 Detectability

Detectability (or odour threshold) refers to the minimum concentration of odorant stimulus necessary for detection in some specified percentage of the test population. The odour threshold is determined by diluting the odour to the point where 50% of the test population or panel cannot detect the odour any more. The original *odour concentration* of an odour sample can be characterised by the number of dilutions to reach this detection threshold. At the detection threshold the odour concentration is 1 odour unit per metre cubed. Threshold values are not fixed physiological facts or physical constants but statistically representing the best estimate value from a group of individual responses. Odour concentration is the most common attribute used to characterise odours. It provides the most common measure to characterise the magnitude of stimulus for determining the other attributes of an odour (the horizontal axis).

A European CEN standard method EN13725 'Air quality – Determination of odour concentration by dynamic olfactometry' for measuring odour concentration is available (CEN, 1999), and is described in the following sections. The European odour unit (ou_E) is pegged to a well-defined reference material, through the exclusive use of trained assessors selected for their specific sensitivity to the reference odour of n-butanol. In this manner the ou_E has been made traceable:

$1\ ou_E.m^{-3} \equiv 40$ ppb/v n-butanol.

The standardisation of olfactometric measurement procedures in the late 1990's has brought significant improvements to the reproducibility of odour detection thresholds and odour concentration. An Interlaboratory Comparison for Olfactometry (ICO) was held in which European laboratories, including UK laboratories, participated with a view to validating the proposed method in practice (van Harreveld, 1997). The results of the ICO were accepted by CEN Technical Committee 264 'Air Quality' and demonstrated that the quality requirements of EN13725 were attainable in practice. A subgroup of laboratories compared results obtained for a practical odour, which indicated that the performance could not only be attained for the reference odour n-butanol, but also for practical odours. This provides support for the transferability of performance characteristics from the reference odour to the wide range of odours in the environmental practice. (van Harreveld, Heeres, Harssema, June 1999)

3.1.2 Measurement of odour concentration using olfactometry.

Odour measurement is aimed at characterising environmental odours, relevant to human beings. As no methods exist at present that simulate and predict the responses of our sense of smell satisfactorily, the human nose is the most suitable 'sensor'. Objective methods have been developed to establish odour concentration, using human assessors. A draft European CEN standard applies to odour concentration measurement:
CEN EN 13725:1999, Air quality - Determination of odour concentration by dynamic olfactometry, CEN/TC264/WG2 'Odours', 1999

Figure 4 Dynamic olfactometry with human assessors, to measure odour concentration according to EN13725, photo courtesy of OdourNet UK Ltd.

The odour concentration of a gaseous sample of odorants is determined by presenting a panel of selected and screened human subjects with that sample, in varying dilutions with neutral gas, in order to determine the dilution factor at the 50% detection threshold (D_{50}). The odour concentration of the examined sample is then expressed as multiples of one European Odour Unit per cubic meter [$ou_E \cdot m^{-3}$] at standard conditions.

3.1.3 The unit of measurement

The odour unit is a difficult unit to define, because it relates a physiological effect to the stimulus that caused it. The stimulus, in this case, can be a multitude of substances. The way in which the response of our sense of smell is reduced to a single value of a parameter amounts to a gross simplification of the rich spectrum of sensory information that is actually perceived by the brain. Such a simplification may be useful, however, in describing potential effects. The reduction of a very complex set of physiological processes to a simple parameter is methodologically very similar to expressing the effects of toxic substances on an organism as the LD_{50}, indicating the dose that causes a lethal effect in 50% of a well-defined test population. The complex physiological response is regarded as the unifying reaction that can be caused by a wide range of substances, at an equally wide range of dosages. In general terms, this approach can be used to describe the potential of a certain amount of a substance to cause a physiological effect, by expressing the dose as a multiple of the dose that would cause an effect in 50% of a population. The definition and use of the unit are highly analogous to that of the odour unit. In odour research the D_{50} could be described as the 50%

of a population that can detect a sensory stimulus. In the past odour researchers have not used populations of standard test subjects, and have only related the physiological response to the number of dilutions of the dose of a sample to be measured. That practice implies a fundamental inability to compare the dosage of the samples through other means than the population itself. This can only be justified if the researcher is convinced that the samples of the population are sufficiently large to compensate for biological variability within this population. This assumption, however, cannot be fulfilled in the practice of odour measurement. The small sample from the population (4-8 subjects, more or less randomly chosen) is far too limited a sample to be representative, knowing the variability of sensitivity within the population. This practice does not comply with statistical requirements as used in toxicological experimental design, as the sample size from the population required to be representative (hundreds) is far larger than the regular number of panel members used in olfactometry for environmental applications.

The solution is to standardise the test subjects, used to assess the sensory response. Reproducible results can be obtained by selecting panel members with a known sensitivity to an accepted reference material (now n-butanol CAS-nr [71-36-3]). The choice for a small number of panel members in EN13725 (1999) is based on optimum performance of the measurement, not to represent population (van Harreveld, Heeres, 1995). The assumption made is that the sensitivity for the reference odorant will be a predictor for sensitivity to other substances. The assumption of transferability of the performance parameters assessed for n-butanol to an industrial odour is supported by the results of the validation of the EN13725 standard (van Harreveld, Heeres 1997 and van Harreveld, 1997). The dose of other substances and mixtures is then expressed in multiples of the dose that would elicit a physiological reaction equivalent to that of the reference. In practical terms: The European odour unit [ou_E] is that amount of odorant(s) that, when evaporated into 1 cubic meter of neutral gas at standard conditions, elicits a physiological response from a panel (detection threshold) equivalent to that elicited by one European Reference Odour Mass (EROM), evaporated in one cubic meter of neutral gas at standard conditions.

One EROM, evaporated into 1 cubic meter of neutral gas at standard conditions, is equivalent to the D_{50} physiological response (detection threshold), assessed by an odour panel in conformity with this standard, and has, by definition, a concentration of 1 $ou_E \cdot m^{-3}$. There is one relationship between the ou_E for the reference odorant and that for any mixture of odorants. This relationship is defined only at the D_{50} physiological response level (detection threshold), where:

1 EROM (for n-butanol, CAS 71-36-3) ≡ 1 ou_E for the mixture of odorants.

This linkage is the basis of traceability of odour units for any mixture of odorants to that of the reference odorant. It effectively expresses odour concentrations in terms of ‘n-butanol mass equivalents’.

The odour concentration is expressed as a multiple of one ou_E in a cubic meter of neutral gas. The odour concentration can only be assessed at a presented concentration of 1 $ou_E \cdot m^{-3}$. The odour concentration, in $ou_E \cdot m^{-3}$, can be used in the same manner as mass concentrations ($kg \cdot m^{-3}$).

Note: When using odour concentrations one should be aware that the relationship between the *odour intensity* and the *odour concentrations* is not linear, and may be a different relationship for different (mixtures of) odorants.

3.1.4 Odour concentration measurement using quantitative olfactometry

The odour concentration of a gaseous sample of odorants is determined by presenting a panel of selected and screened human subjects with that sample, varying the concentration by diluting with neutral gas, in order to determine the dilution factor at the 50% detection threshold ($Z_{50} \equiv \bar{Z}_{\mathrm{ITE,pan}}$). At that dilution factor, the odour concentration is 1 $\mathrm{ou_E \cdot m^{-3}}$ by definition. The odour concentration of the examined sample is then expressed as a multiple (equal to the dilution factor at Z_{50}) of one European Odour Unit per cubic metre ($\mathrm{ou_E \cdot m^{-3}}$) at standard conditions for olfactometry (Room temperature (293 K), normal atmospheric pressure (101,3 kPa) on a wet basis).

The measurement must be carried out with a selected panel. The method should comply fully with the CEN standard EN13725.

The performance of odour concentration measurements has been defined in the performance criteria of the standard. These imply that for one single measurement result, the 95% confidence interval will be:

The geometric repeatability of the sensory calibration with n-butanol is r' ≤ 3, complying with the EN13725. The confidence limits for a value x for two measurements (k=2) is:

$$x \cdot 2.09^{-1} \leq x \leq x \cdot 2.09$$

In other words, if the real concentration is 1000, the result of analysis will in 95% of cases lie in the interval between 571 and 1752 $\mathrm{ou_E \cdot m^{-3}}$. Analysing more than one replicate of a sample can reduce the uncertainty. Figure 5 shows the 95% confidence interval for replicated measurements, for the repeatability that is required in the EN13725 standard.

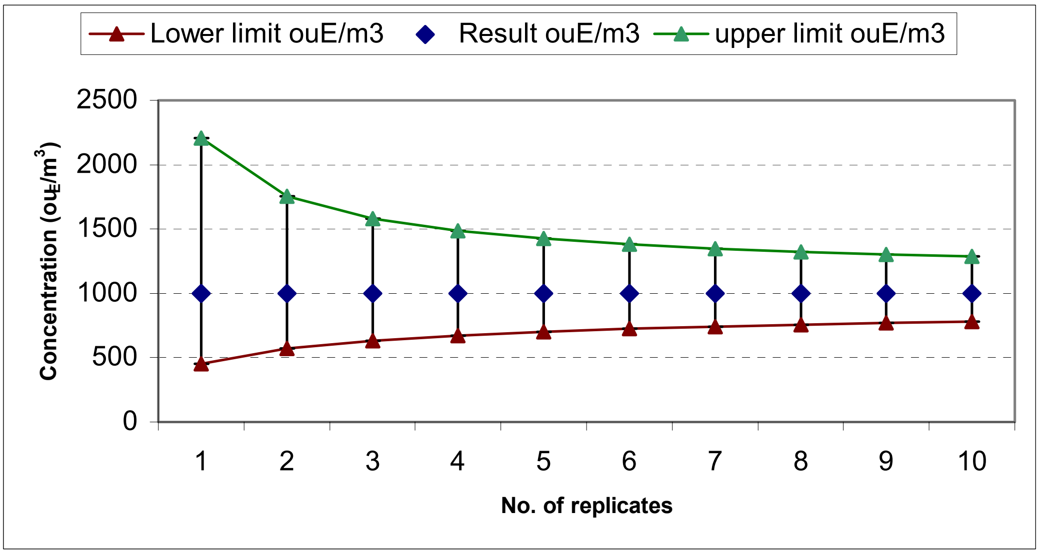


Figure 5 Confidence intervals for replicated measurements using dynamic olfactometry according to EN13725. The true value is assumed to be 1000 $\mathrm{ou_E \cdot m^{-3}}$

For the assessment of the efficiency of an odour abatement unit, the repeatability is an important consideration. Again assuming the repeatability required in the CEN standard EN13725, Figure 6 gives confidence intervals for the filter efficiency in relation to the number of samples taken both before and after the abatement unit *n,* when the actual efficiency is 90%.

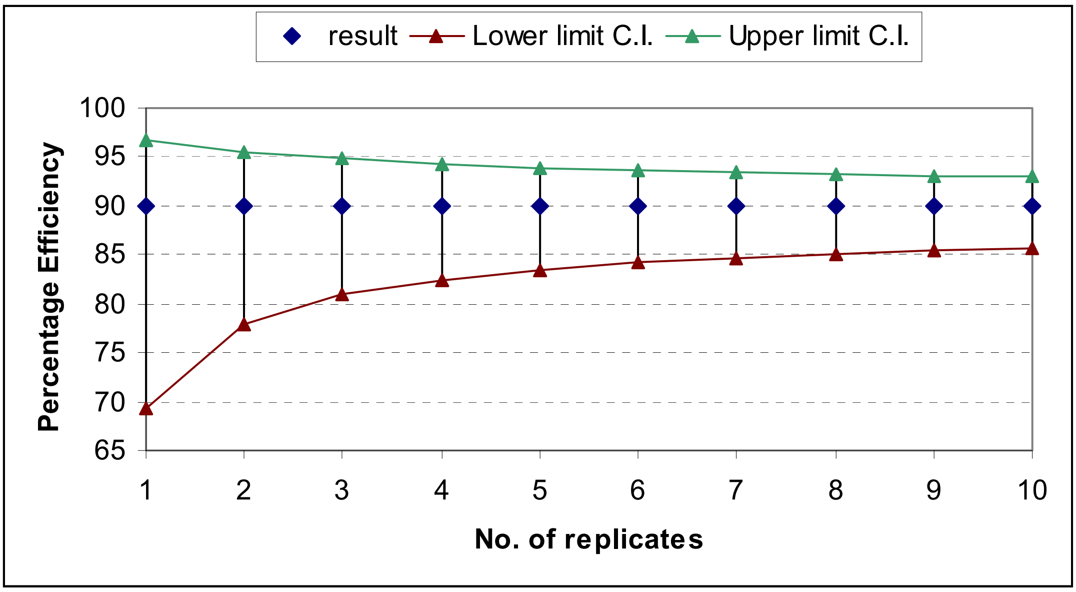


Figure 6 - Confidence intervals for determining the abatement efficiency of an odour abatement system, as a function of the number of samples collected both before and after treatment.

3.2 Intensity

Intensity is the second dimension of the sensory perception of odorants, which refers to the perceived strength or magnitude of the odour sensation. Intensity increases as a function of concentration. The relationship between perceived intensity and the *logarithm* of odour concentration is linear.

Odour intensity refers only to the magnitude (strength) of the perception of an odour. Intensity has a second meaning, in that it can refer to the magnitude of the stimulus causing the perception.

The relationship between perceived intensity I and the stimulus may be described as a theoretically derived logarithmic function according to Fechner:

$$S = k_w \cdot \log {}^{I}\!/_{I_o}$$

where

S	perceived intensity of sensation (theoretically determined)
I	physical intensity (odour concentration)
I_o	threshold concentration
k_w	Weber-Fechner coefficient

or as a power function according to Stevens:

$$S = k \cdot I^n$$

where

S	perceived intensity of sensation (empirically determined)
I	physical intensity (odour concentration)
n	Stevens' exponent
k	a constant

Which one of these two descriptions applies depends on the method used. To date no theory has been able to derive the psychophysical relationship from knowledge about the absolute odour threshold of various substances.

The method for measuring intensity is derived from the following standard documents:
VDI 3882:1997, part 1, *Determination of Odour Intensity,* Düsseldorf, Germany.

The principle of measurement is presentation of the odour to human assessors in an odour panel, at varying degrees of dilution, hence varying perceived intensity.

The members of a panel of assessors are asked to indicate perceived intensity at each presentation as a value for the perceived intensity *I* on the seven point intensity scale:

0	no odour
1	very faint odour
2	faint odour
3	distinct odour
4	strong odour
5	very strong odour
6	overwhelming odour

The values for *I* are then plotted against the logarithm of the odour concentration or the dilution factor. The regression line characterises the relationship between perceived intensity and odour concentration. The point where the regression line intersects with the horizontal axis is equivalent to the detection threshold.

By comparing the slope of the regression line for different odours they can be characterised. Some odours cause rapid increase in perceived intensity (such as H_2S). Other odours cause only a slow rise of perceived intensity, such as commercial toilet air fresheners that are designed to be perceived at a similar intensity, regardless of dilution.

An example of the relationship between intensity and concentration is presented in Figure 22, section 0.

3.3 Odour quality (descriptive)

Odour quality is the third dimension of odour. It is expressed in descriptors, i.e. words that describe what the substance smells like. This is a qualitative attribute, which is expressed in words, such as ‘fruity’.

The character of an odour may change with concentration level, for example, hydrogen sulphide at levels of 20 ppm or above ceases to be perceived as a "rotten egg" smell.

The American Society for Testing and Materials (ASTM) have developed a standardised set of 146 descriptors to characterise an odour (Dravnieks, 1983). In the evaluation procedure, human panel members are asked to indicate which descriptors apply to the odour in question. Their responses are collated into an index for each descriptor. An odour atlas has been prepared using this method, establishing descriptive odour profiles for over 100 odorous compounds, using a panel of 120 individuals.

Dravnieks e.a. (1984) proposed a method to derive a hedonic tone score from the odour profile of descriptors, and demonstrated that a reasonably strong correlation exists between the hedonic tone derived from descriptors and that derived from actual hedonic tone measurements, as described in the following section.

3.4 Hedonic tone

Hedonic Tone is the fourth dimension of odour. This is a category judgement of the relative like (pleasantness) or dislike (unpleasantness) of the odour. The method for measuring hedonic tone is derived from the following standard document:
VDI 3882:1997, part 2; *Determination of Hedonic Tone,* Düsseldorf, Germany

The principle of measurement is presentation of the odour to human assessors in an odour panel, at varying degrees of dilution; hence varying perceived intensity and hedonic tone.
The members of a panel of assessors are asked to indicate perceived hedonic tone at each presentation as a value from the nine-point hedonic tone scale:

+4	very pleasant
+3	pleasant
+2	moderately pleasant
+1	mildly pleasant
0	neutral odour / no odour
-1	mildly unpleasant
-2	moderately unpleasant
-3	unpleasant
-4	offensive

For each concentration level, the mean of the values for H of all panel members is calculated, and plotted against the odour concentration in $ou_E \cdot m^{-3}$. A fictitious example of the plotted result is presented in the figure on this page. Using a suitable curve fitting procedure a line can be fitted through the points obtained in the experiment. Using this interpolation, characteristic values can be derived from the plot, such as the odour concentration at H = -2. This dimension is one of the candidates for expressing the annoyance potential of odour, subject to resolving the methodological issues.

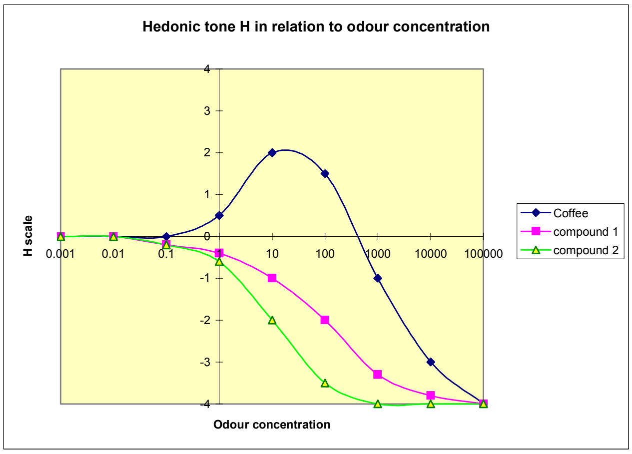


Figure 7 Hedonic tone as a function of odour concentration

3.5 Annoyance potential

Annoyance potential is a proposed attribute to quantify the propensity of an odour to cause annoyance within a population when exposed to this odour intermittently, over a long period of time. Annoyance potential is likely to be a function of both odour quality and hedonic tone in addition to perceived intensity. Hedonic tone and perceived intensity are not independent variables, as these parameters both depend on the odour concentration, expressed in dB_{od} or $ou_E \cdot m^{-3}$. However, the exact nature of the interaction between the dimensions of odour, which may help to define the potential of that odour to cause annoyance, has yet to be clarified. Once a method is available it will help in the definition of differentiated air quality standards for specific odours.

A government funded development programme to arrive at a method for annoyance potential assessment is currently ongoing in the Netherlands, building on the conclusions of a feasibility study (van Harreveld e.a., 1999) and is planned to yield a validated method, suitable to be standardised, in December 2001.

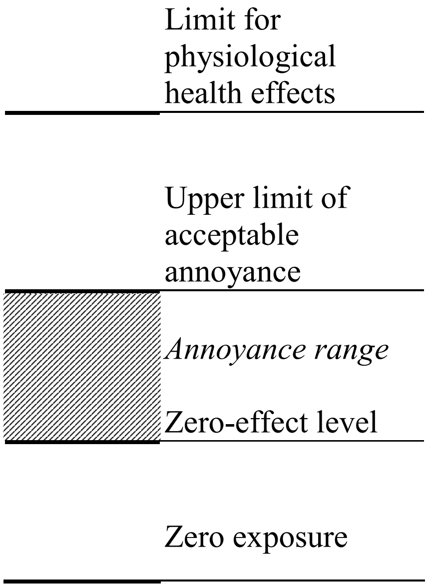
4. ANNOYANCE CAUSED BY AMBIENT STRESSORS

This chapter describes the general approach for assessment of environmental stressors, and identifies the similarities between odour and other environmental stressors such as noise and artificial light in terms of the cognitive perception process and complaint behaviour in the UK and overseas.

The relationship between perception of odours and health and well-being, and the process that can lead from perception of environmental odours to odour annoyance is presented. A framework of concepts relating to odour annoyance are proposed and compared to the current science and techniques applied for assessment of environmental noise. Commonalities between odour and noise are highlighted to establish the context of the odour issues within the existing noise framework regulatory framework.

4.1 Ambient stressors considered in the general framework of assessing health effects

In setting environmental quality targets the typical approach is to establish a zero effect level and a level where physiological adverse health effects will occur (e.g. demonstrated physiological damage or effects due to long term exposure). These levels provide the ‘objective’ limits of the range of exposure that can be supported by scientific evidence. The intermediate range is the ‘annoyance range’. Where to set a limit value, within this range, requires policy decisions to set limit and/or target levels that are compatible with the requirements and aspirations for environmental quality within a particular society, at a particular time.



To assist policy decisions, investigations using survey techniques can assist in setting an upper limit of acceptable annoyance that may be used to limit the annoyance range somewhat further.

For exposure to substances with potential health effects, toxicological and epidemiological studies can provide relatively hard data on these limit values. Well-established mechanisms exist to derive exposure limits from such information, taking the nature of the potential damage caused into account by using a variety of safety factors.
Many potentially toxic substances can only be detected by instrumental methods, at environmentally relevant exposure levels. In other cases, our human senses are capable of directly sensing, detecting and judging the presence and magnitude of environmental factors, such as light, noise and odour. When these factors are present at levels that lead to a negative appraisal, we speak of ambient stressors.

Our senses are well adapted to handle a wide range of sensory input. Safety factors are in-built, so that the stimulus causes negative appraisal at levels that are considerably below those that would cause the risk of physiological harm.

For such ambient stressors, the range in which exposure causes negative appraisal, or annoyance, can be considerable. When exposure at that level occurs regularly, the annoyance becomes a more or less chronic factor affecting our well-being. If this happens we speak of nuisance. (The concept of nuisance is not used in its legal meaning here, see section 0 for definitions).

The appraisal of sensory ambient stressors is not simple or straightforward. It is not so much the eye, the ear or the nose that determines appraisal, but the brain that compares the incoming information with its sensory history, associated memories and experiences, the current behavioural status of the individual etc. The brain then decides, somehow, what the relevance of the information is, within the full range of sensory inputs. The outcome of this process depends both on the individual, and the behavioural and environmental context of the moment, which contributes to the wide range of responses that can occur in individuals, when exposed to similar sensory input. For example, whether or not music results in annoyance is not only determined by the volume of music, but is dependant on the type of music and whether we are in mood to listen to loud music and/or music of that kind.

In spite of the complexity that arises from all these variables, a society can agree on levels of exposure to ambient stressors that are generally considered acceptable. We have a comprehensive regulatory system for limiting exposure to noise, in order to avoid nuisance. There are many similarities between annoyance induced by noise, induced by odour or induced by exposure to unwanted artificial light.

The cognitive appraisal that follows sensory perception is similar for all sensory information. The reason that the noise of a dripping tap can become seriously irritating is, after all, more driven by cognitive appraisal factors than by the acute loudness of the noise. Similarly, an odour with a negative connotation can be appraised as annoying, even at low perceived intensity, when it can only just be recognised.

The cognitive processes that lead from annoyance to nuisance for other sensory stressors in the environment, such as noise and artificial light, can help us to understand how odour related annoyance and nuisance arise. For this reason, the mechanisms that are considered to lead to annoyance and the regulatory frameworks that exist for these sensory ambient stressors are outlined in the sections below in some detail.

4.2 Complaints induced by ambient stressors, such as noise and odour

Complaints are the first symptom of odour annoyance existing to such a degree that it requires involvement of the relevant public authority. From a regulatory perspective, complaints are generally the driving force behind action relating to statutory nuisance and Common law nuisance actions. The same is true to a degree from the statuary regulatory framework (i.e. IPC). However, the latter aims to identify suitable controls to minimise nuisance before complaints are received. An overview of the legislation framework for regulation of odours is provided in Annex B.

Odour is typically the second most common cause of complaints about the environment, after noise. The rate of complaint can vary, depending on actual differences in exposure and incidence of annoyance, but also because of other effects, such as:

- Quality of complaint registration
- Accessibility of complaint registration
- Trust in potential for improvement through complaints
- ‘Complaint threshold’ characteristics of the culture in question

In general, complaints are a strong indicator that odour annoyance is an issue. Absence of complaints is not necessarily an indicator of absence of odour annoyance.

The Chartered Institute of Environmental Health (CIEH) compiles complaints data in relation to noise and odour in the United Kingdom. The numbers of complaints are reported by individual Environmental Health Authorities on a voluntary basis. National statistics for the UK as a whole are not available. The Authorities that report vary from year to year, which makes comparison of absolute numbers of complaints from year to year difficult. Those figures that are reported as number of complaints per million inhabitants are more suitable for comparison, although again year to year comparisons may be affected by random factors, such as the actual authorities reporting their complaints data. In general, the robustness of the CIEH data is questionable on a year-to-year basis.

Other governmental and non-governmental bodies also undertake research regarding the nature and frequency of complaints. For example, the National Society for Clean Air and Environmental Protection (NSCA) undertook a National Noise Survey, published in June 2000 (NSCA2000). The complaint rate for odour induced complaints for the period 1988 to 1999 is presented in Figure 8.

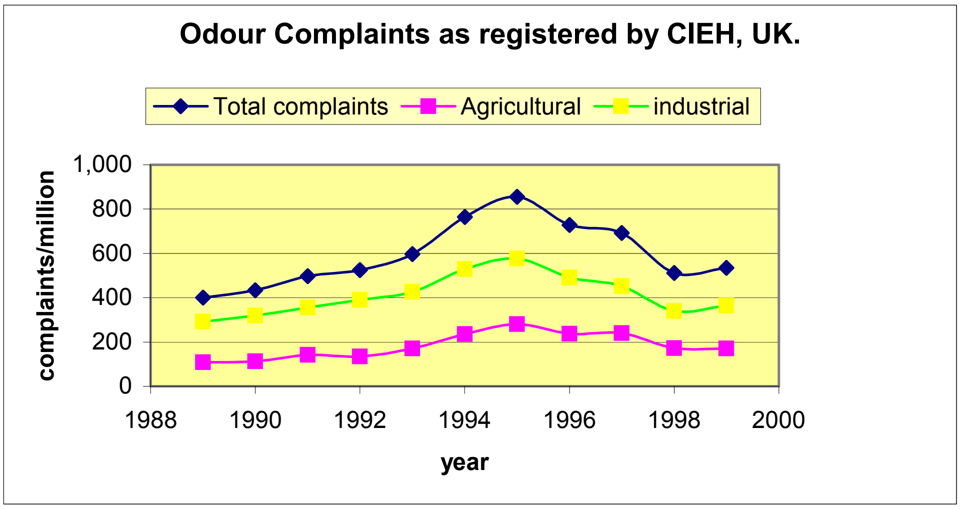


Figure 8 Total odour complaints in the UK, as registered by the CIEH, for the period of 1988-1999. Source: Chartered Institute of Environmental Health.

Most odour complaints are attributed to industrial sources, with between 30% and 50% of the total complaint rate attributed to agricultural causes.

The total complaint rate rose steadily until 1995, when it reached approx. 850 per million inhabitants (or $850 \cdot 10^{-6}$ per inhabitant). In the following years the rate seems to drop to $500 \cdot 10^{-6}$ per inhabitant. It is not clear whether this reduction represents an actual drop in complaint rate or a difference in the effectiveness of collecting and registering these complaints. The underlying data are probably not sufficiently robust to draw any firm conclusions on year-to-year changes in complaint rates.

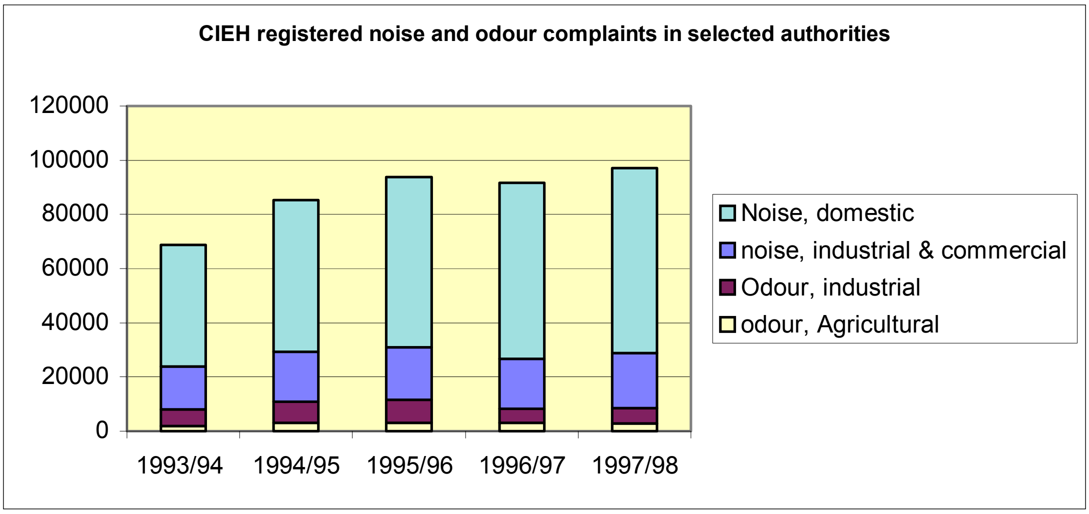


Figure 9 odour and noise complaints registered in selected authorities in the UK, 1993-1998. (Chartered Institute of Environmental Health)

In data presented by CIEH, for a number of selected authorities that have consistently reported over a number of years (1993 to 1997), we can see that the total number of reported complaints show similar overall trends from year to year for odour and noise induced complaints, see Figure 9.

This would suggest that the differences from year to year are caused by the willingness to register complaints, or in the registration process itself, rather than in differences in exposure. After all, the exposure to domestic noise is unlikely to differ significantly from year to year.

The comparison between complaints for odour and noise shows that the complaints about domestic noise dominate the registration of the CIEH. The absolute numbers of noise-induced complaints, and the rate of complaint per million inhabitants, as recorded by the CIEH for the year 1997/98, is presented in Table . The rate of complaint for industrial noise, at $615 \cdot 10^{-6}$ per inhabitant, is 1½ times higher than the rate of complaint for industrial odour, at $452 \cdot 10^{-6}$ per inhabitant. On the basis of the symptom of complaints, the argument that regulatory policy for industrial odours of a similar magnitude as that for noise would be justified, including a similar allocation of resources to the control of exposure.

The *total* number of noise-induced complaints recorded by the CIEH is far greater than the industrial complaint rate. The complaint rate for domestic noise is, in fact, more than 8 times the rate for industrial odours, at $5050 \cdot 10^{-6}$ per inhabitant for 1997/98.

	Industrial	Commercial / Leisure	Construction / Demolition	Domestic	Vehicles	Equipment in the Street
Complaints received by EHOs	17,737	29,779	8,232	148,006	4,738	3,835
Complaints per million people	615	1,032	285	5,050	167	133

Table 2 Noise complaints registered by Environmental Health Officers and prosecutions in the UK, 1997-98 (source: CIEH 2001)

Data is also available for ambient sources, where the NSCA (2000) found that pubs and clubs are by far the largest cause of noise-induced complaint, followed by industry, and construction. Traffic noise, although widely identified as a cause of annoyance, promotes relatively few complaints. The reason for this is likely to be related to the lack of action that can be taken as result of such complaints.

Domestic noise is a frequent cause for complaints. Noise caused by television sets, while seldom annoying for the viewer, is clearly a significant case of nuisance for those neighbours who can overhear it, even after attenuation by a wall. This suggests that the status of the person and the context of the noise, rather than just the noise pressure in dB, is a determining contributing factor to causing annoyance. Amplified music is also a significant cause of complaints. Does the type of music played determine the annoyance level? These questions are apparently relevant to both the appraisal of noise as for the appraisal of odour.

The number of people actually experiencing the effects of annoyance caused by odour and noise appears to be much higher than the number of registered complaints. In some countries, annoyance caused by ambient stressors is followed by systematic year-on-year surveys. The prevalence of annoyance as measured by survey is typically much higher than the number of registered complaints.

This can be demonstrated by presenting data from the Netherlands. Figure 10 shows the number of people annoyed by odours as measured in a long-term national survey by the National Bureau for Statistics in the Netherlands, for the period 1985-1996. The survey methodology is described in section 0.

The percentages of people experiencing annoyance, as determined by survey, are 16 to 21 %, or $120.000 \cdot 10^{-6}$ to $210.000 \cdot 10^{-6}$ per resident. The causes of the reported annoyance are broken down as follows:

- 45% Industry
- 15% Agriculture
- 35% Traffic
- 5% Domestic source.

The prevalence of annoyance is significantly higher than rates for odour-induced complaints, which is between $5000 \cdot 10^{-6}$ and $100,000 \cdot 10^{-6}$ complaints per resident per year in the heavily industrialised area around Rotterdam. The greater complaint rate of $100,000 \cdot 10^{-6}$, that is 10% of residents *filing a registered complaint in one year*, can be considered a maximum, occurring in a neighbourhood close to refineries and harbour in the Rotterdam area.

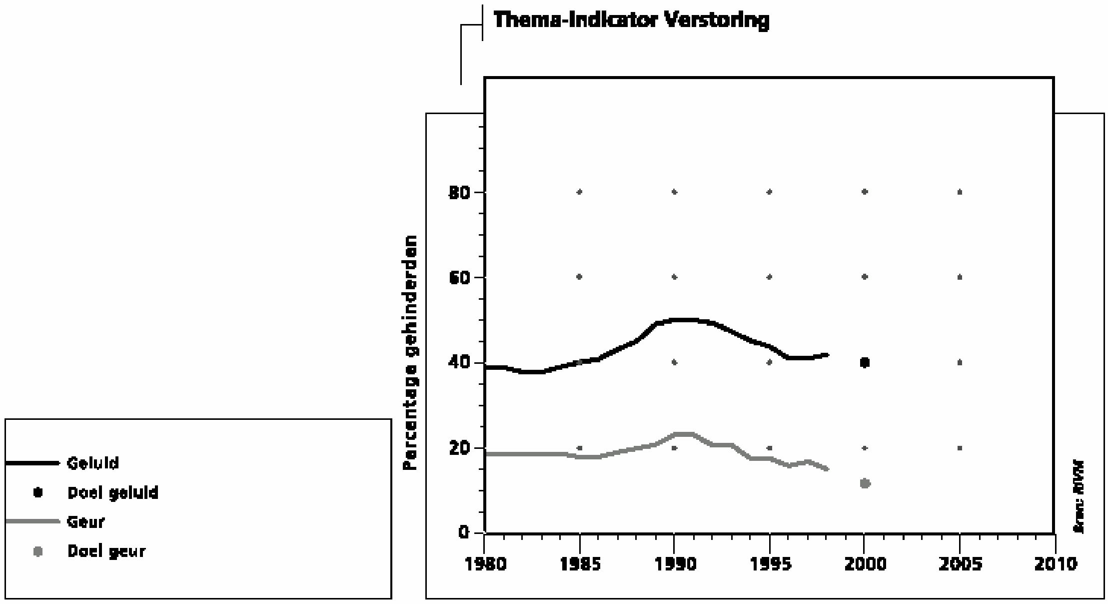


Figure 10 Percentage of individuals in the population indicating occasional annoyance by odour (geur) and noise (geluid) on the basis of a Continuous Living Environment Survey in the Netherlands. The policy target for odour is a percentage of 12% in 2000, and 40% for noise. Source: CBS, 1999 see also Kruize, 1998.

The complaint rate reported for odour-induced complaints in the Netherlands, of approx. $5000 \cdot 10^{-6}$ is more than 8 times higher the rate reported by the CIEH for reporting authorities in the UK, at approx. $800 \cdot 10^{-6}$ per inhabitant. This difference is likely to be at least in part caused by differences in the registration and accessibility of complaint registration infrastructure.

The complaint and survey data presented in this section suggests that the number of people experiencing odour annoyance in the UK is significant, and is likely to be between a low estimate of a few percent and a high estimate of up to 10-20% of the UK population, which would be comparable to the magnitude as surveyed in the Netherlands.

An improvement of statistical data on annoyance caused by ambient stressors in the United Kingdom would help in managing the issues involved. However, it should be emphasized that odour and noise problems are often a local issue, and can be much more of an issue for those involved than can be adequately described by overall national statistics.

4.3 Odour induced annoyance: The process leading from odour release to perception to nuisance

Odour nuisance can develop after long-term intermittent exposure to odours that cause a negative appraisal in the individual concerned. It has to do directly with the way we value our environment. It is not a straightforward process. Our attitudes towards the source, the inevitability of the exposure and the aesthetic expectations regarding our residential environment are some of the less tangible factors that are relevant to the probability of experiencing nuisance. Once the balance tips, and an ambient stressor, such as an industrial odour, becomes a nuisance to an individual, it is very difficult to reverse the process. What used to be a faint odour has now become a signal for annoyance. Once the first complaint has been made, the problem is much more serious for all those affected than before. The mechanism that leads from an emission of odorants to atmosphere to actual odour nuisance is quite complex. It involves the following main factors:

- The **characteristics of the odour** that is released (detectability, intensity, hedonic tone, annoyance potential);
- Variable **dilution in the atmosphere** through turbulent dispersion (turbulence or stability of boundary layer, wind direction, wind speed, etc.);
- **Exposure of the receptors in the population** (location of residence, movement of people, time spent outdoors etc.);
- **Context of perception** (i.e. other odours, background of odours, activity and state of mind within the perception context);
- **Receptor characteristics** (exposure history,

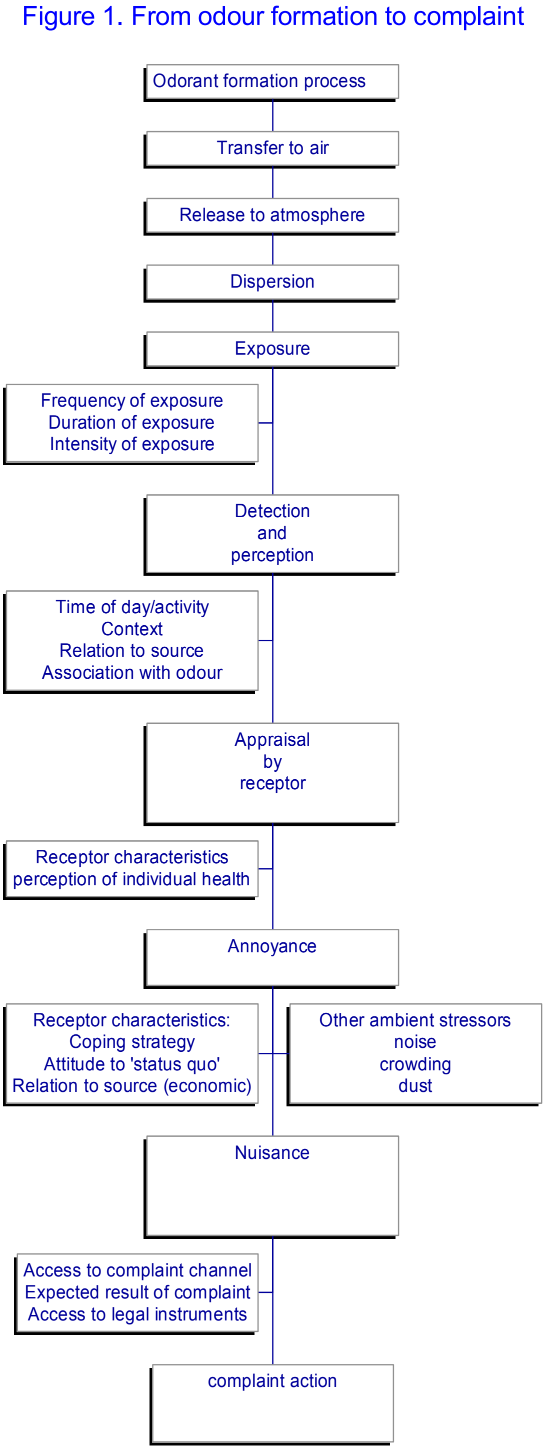


Figure 11 Pathway of odour from production to receptor

association with risks, activity during exposure episodes, psychological factors such as coping behaviour, perceived health and perceived threats to health).

This process can be summarised as:

formation of odorants → transfer to atmosphere → atmospheric dispersion → exposure → population → perception → appraisal →annoyance →nuisance→complaints

When we look at the underlying mechanisms, the factors that play a role are more diverse and mutually interactive, as is illustrated in Figure 11.

For practical purposes, such as regulatory use, the complex relationship between annoyance (effect) and exposure to odours (dose) can be described in a simplified model that does not take into account all these different factors. The dose effect model linking 'exposure to odours' to 'nuisance' is typically described as the relationship between modelled exposure and annoyance as measured by a standardised telephone questionnaire or, alternatively, complaint records. Epidemiological methods are used to describe this relationship.

The exposure is typically quantified in terms of a frequency of occurrence of hourly average concentrations above a certain limit odour concentration; e.g. 5 odour units per metre cubed ($ou_E \cdot m^{-3}$) as a 98-percentile of hourly averages of odour concentration for a year with average meteorology. In short notation: $C_{98,\ 1\text{-hour}} = 5\ ou_E \cdot m^{-3}$. This measure of exposure is calculated from an estimated or measured odour emission from the source, and meteorological and terrain input data, using an atmospheric dispersion model.

Air quality criteria for odour can be set on the basis combining calculated exposure with knowledge of the dose response relationship to quantify and assess odour impact. However, this relationship will not be the same for every community. It is determined by factors such as crowding, expectations of environmental quality, economic priorities etc.

Although odour can have direct effects on well-being, and hence on health, it is to some degree an aesthetic factor in environmental quality. To set environmental exposure criteria with a view to avoiding odour nuisance is therefore not only a scientific, but also a political process. The range of political discretion is limited, however. Unlike other air pollutants, every citizen with a functioning nose can assess odour real-time. The appraisal is immediate and the outcome is readily communicated to the relevant authority in the form of complaints.

4.3.1 A framework of concepts, terms and definitions for odour related effects

Most work on environmental odours has been aimed at managing odour nuisance as a result of long term intermittent odours caused by stationary sources.

Although a large volume of literature exists on odours, the terminology used to describe its effects is often confusing and its use imprecise. To enable a more effective discussion of odour annoyance and its contributing factors, a number of definitions and concepts have been proposed recently (Van Harreveld, 1999). These operational concepts, which are used in this sense throughout this report, are presented below. These definitions may differ from the interpretation of these concepts in, for example, legal considerations.

Nuisance

Nuisance is the cumulative effect on humans, caused by repeated events of annoyance caused by exposure to an ambient stressor over an extended period of time, that leads to modified or altered behaviour.

This behaviour can be active (e.g., registering complaints, closing windows, keeping ‘odour diaries’, avoiding use of the garden) or passive (only made visible by different behaviour in test situations, e.g. responding to questionnaires or different responses in interviews). Odour nuisance can lead to infringement of our sense of well-being, and hence a negative health effect. Nuisance occurs when people are affected by an odour they can perceive in their living environment (home, work environment, recreation environment) and:

- the appraisal of the odour is negative
- the perception occurs repeatedly
- it is difficult to avoid perception of the odour
- the odour is considered a negative effect on their well-being

Annoyance

Annoyance is the complex of human reactions that occurs as a result of an immediate exposure to an ambient stressor (e.g. odour) that, once perceived, causes negative cognitive appraisal that requires a degree of coping.

Annoyance potential

Annoyance potential is the attribute of a specific odour (or mixture of odorants) to cause a negative appraisal in humans that requires coping behaviour when perceived as an ambient odour in the living environment.

Annoyance potential indicates the magnitude of the ability of a specific odorant (mixture), relative, to other odorants (mixtures), to cause annoyance in humans when repeatedly exposed to weak to moderate perceived intensity in the living environment. It is an attribute of an odour that can cause annoyance or nuisance.

Nuisance potential

Nuisance potential is the characteristic of an exposure situation, which describes the magnitude of the nuisance that can be expected in a human population when exposed in their living environment to an ambient stressor (e.g. odour) intermittently, but over an extended period of time.

Nuisance potential is a function of many factors, such as the attributes of the odorant (mixture) in question, the frequency and dynamics of variation of the exposure (caused both at source and as a result of atmospheric dispersion) and attributes of the specific population that is exposed.

Nuisance sensitivity

Nuisance sensitivity is an attribute of a specific population (or an individual) that indicates the propensity, relative to that of other individuals or populations, to experience nuisance when exposed in their living environment to an ambient stressor (e.g. odour) intermittently, but over an extended period of time.

4.4 Noise induced annoyance: an introduction to concepts and similarities to odour issues

Noise and odour are both ambient stressors that can cause annoyance. To facilitate development of odour exposure guidelines it is therefore useful to study the concepts that were developed to characterise noise, as the study of noise as an ambient stressor and the regulation of exposure has a longer history than that for odour. This section describes a variety of concepts that have been developed to characterise noise. Its contents do not, in any way, reflect current Environment Agency policy or practice towards regulating noise exposure in the UK. On the contrary; this section aims to show that the practice of regulating noise deliberately uses a limited set of relatively straightforward measured parameters to effectively regulate exposure as an ambient stressor for which the cognitive aspects of appraisal are complex, similar to those that apply to odours.

4.4.1 Psychological factors contributing to noise induced annoyance

The interplay of physical, physiological and psychological factors that determine whether appraisal of exposure to sound is positive, negative, annoying or a cause for nuisance is highly complex. The outcome of a particular exposure situation will vary from individual to individual, and also depend on external factors that bear no relationship to the nature of the noise. The context of exposure, exposure history associations etc. are examples. As an illustration, loud music at a party may cause annoyance to one person, but be acceptable to another who enjoys that music style. A dripping tap, which was hardly noticed during the daytime whilst the receptor was active, will seem to increase in perceived volume and potential annoyance during the night. Comparisons between objective and subjective measures have been attempted in research. These studies have centred on the use of four scale types: nominal, ordinal (determination of relative magnitudes - similar to the intensity scale used in hedonic tone assessment VDI 3882:1997), interval and ratio.

It is however interesting to note that despite extensive and continued research, no suitable method has been adopted thus far to measure the attribute of ‘annoyance potential’ for noise. In practice, surveys of social behaviour aimed at specific cases are used, such as complaints data, as adopted widely by local authorities (NSCA, 2000).

4.4.2 Introduction to noise and its characterisation as an ambient stressor

For the purpose of establishing a dose-effect relationship for noise induced annoyance, many factors have to be considered, including the source of the noise, the response of the individual and the acoustic characteristics of the noise itself. The 'acoustic characteristics' include the duration and time of day, how often it occurs, the maximum level, the frequency components of the noise and the difference in level between the noise from the source and the background sound level at the receiver.

The average human hearing response to noise varies with frequency as illustrated Figure 12. Our sense of hearing is less sensitive to lower frequencies than to higher frequencies. The detection threshold depends on the characteristics of the noise, just as our sense of smell is more sensitive to some odorants than to others.

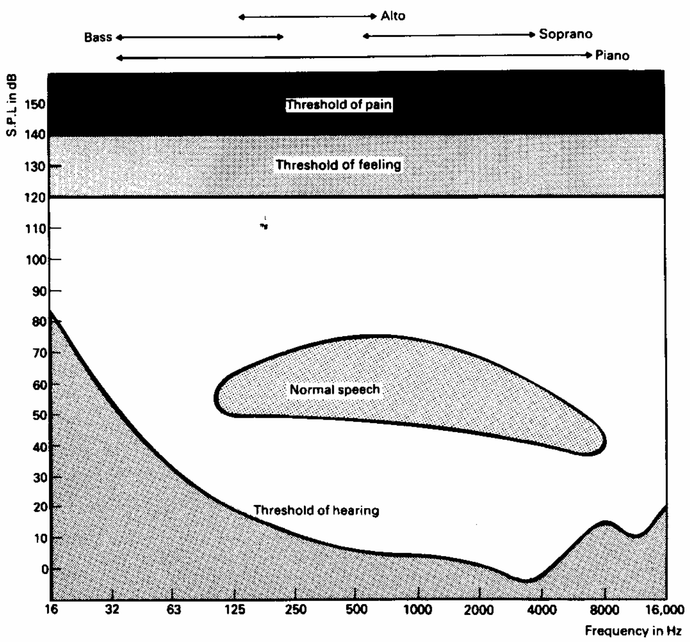


Figure 12 Hearing threshold as a function of frequency for an average person of age 18-25 years. Source: Smith et al, 1996

There are several parameters that can be used to assess noise but the most commonly used and understood unit used sound is the dB(A) scale coupled with an averaging period and statistical analysis. The 'A' denotes the use of a filter which makes the sound level meter's response closer to that of the human hearing as illustrated in Figure 12. This allows a simplification of the sound assessment to the measurement of the physical sound pressure level and no account is taken of undue sensitivity of the receiver.

This approach, involving simplification, is similar to the way in which odour nuisance has been treated in licensing, within the framework of common law. Background information pertaining to the legal framework for avoiding nuisance and its application in licensing is contained in Annex B. The regulations pertaining to environmental noise exposure are briefly summarised in Annex C.

Other units such as *phons* and *sones*, Single Event Level (SEL), Perceived and Effective Noise Level (PNdB and EPNdB), *noys*, Noise Criteria Curves and Noise Rating Curves have been around for many years. However, they are not found in general noise standards and legislation in the England and Wales. The dominant parameters are the $L_{Aeq,T,}$ and the $L_{A90,T}$.

- **$L_{Aeq,T}$**
  The $L_{Aeq,T}$ is the value of the A-weighted sound pressure level in decibels of continuous steady sound, within the time period T, that has the same mean-squared sound pressure as a sound that varies with time (BS 4142:1997).
- **Background Sound Level**
  $L_{A90,T}$ is the A-weighted sound pressure level that is exceeded for 90% of the time interval T, measured using the time weighting F, and rounded to the nearest whole number of decibels (BS 4142:1997).

- **Rating Level**
  $L_{Ar, Tr}$ is a noise index – the equivalent continuous A-weighted sound pressure level during a specified time period with the addition of 5dB(A) for tonal or impulsive characteristics of the sound (BS 4142:1997).

Some of the other parameters are used in architectural acoustics, the Noise at Work Regulations 1989 and noise certification for aircraft.

There is now a growing trend to use frequency analysis (octave, 1/3rd octave and FFT) to assess industrial and commercial noise sources and effects in order to identify troublesome frequencies. Furthermore BS4142: 1997 offers a method of rating noise affecting mixed residential and industrial areas and assists by suggesting the addition of 5dB to the measured level of noise if it has noticeable components.

Hence most acoustic environments are assessed in terms of the single number for the period under consideration without reference to other issues that may contribute to annoyance.

Similarly, the current approach to characterising exposure to odours is usually related to frequency of exceeding odour concentration only, ignoring the nuisance that could be expressed in terms of annoyance potential or the characteristics of the exposed population.

4.4.3 Parameters for describing the 'loudness' or 'noisiness' of sound

This section describes a number of parameters and concepts that have been developed to characterise noise, with a view to describing its perception by humans. Many of these parameters are not used in the regulatory framework in the UK, and are included only to illustrate similarities with concepts that apply to odour perception.

The most important attributes used to describe exposure to sound are (BS7445, 1996):

- Frequency (number of vibrations per second);
- Amplitude (maximum magnitude of a vibration. The amplitude is directly related to the sound pressure at a particular frequency. However, sound usually is a mixture of frequencies, and thus sound pressure is the more relevant attribute than amplitude.);
- Tone (a factor of pitch, quality and strength. Most sounds are not one frequency, but a mixture of frequencies and their harmonics);
- Sound pressure (typically measured as pressure in microPascal (μPa) or as energy in Watt.m^{-2} and then converted in dB, relative to the 'average' human detection threshold for sound at 1000Hz), see also 0.

These attributes will contribute to determining the 'loudness' of a noise as perceived by a human observer. This is a subjective sensory perception, which is determined by the attributes of the noise itself, as listed above, as well as the sensitivity of the perception by ear and the consequent appraisal by the brain. For assessments of exposure for regulatory purposes, the 'normal' sensory acuity for sound is usually used as a reference value, to calculate the sound pressure in dB, relative to the 'average' detection threshold of sound at 1000 Hz (see also section 0 for an explanation of the dB unit). This allows a simplification of the sound exposure assessment to measurement of the physical factors that are usually considered when assessing loudness. No account is taken of hypersensitivity, and the 'normal' sensory acuity is defined as being that possessed by the 'average' person, with 'average' sensitivity to noise. The term 'normal' and 'average' are essentially used in a legal sense here, rather than in a scientific sense where underlying quantitative data on the distribution of sensitivity in the population would be assumed. This approach is similar to the way in which odour nuisance has been treated in common law. Background information pertaining to this issue is contained in Annex B. It is notable that in impact evaluations for noise, the characteristics of the particular group of exposed people in the community is not taken into account in the implementation of noise regulations, other than in a very rudimental way of setting different levels for ‘urban’ and ‘non-urban’ situations.

Measurement of hearing sensitivity in individuals is quite possible, using an audiometer. This uses the signal detection threshold principles that are the common methodological basis for eye tests, audiometry and olfactometry. Figure 12 shows the hearing threshold in dB, for the audible frequency range, for an 18-25 year old with an ‘average’ sensitivity.

It clearly shows that the detection threshold, expressed as sound pressure in dB (with a reference detection threshold at 1000 Hz), varies with frequency. At lower frequencies, the sound pressure needs to be much higher for the noise to be detectable. A parallel can be drawn here with the approach in olfactometry. Just as the human ear is not equally sensitive to noise across the audible frequency spectrum, the olfactory sense shows large differences in sensitivity to the ‘spectrum’ of odorants. In the practice of measurement for environmental purposes, however, noise is reduced to the dB, with a reference level at only one point of the spectrum (1000 Hz). In a parallel approach, exposure to odour can be expressed in odour units, or in dB_{od}, which are both defined using a reference on one point of the ‘odour frequency spectrum’, the reference odorant n-butanol (see section 0. for more detail).

4.4.3.1 Loudness units compared with other noise attributes

Pure tones of differing frequencies may be compared with that of 1000 Hz through adjustment of the amplitude to obtain equal-loudness contours. This loudness level is given in *phons*. However, the *phon* scale is also not additive for different sounds, and hence another unit, *sone*, must be used (see Figure 13). Furthermore, when noise is other than pure, Stevens’ phons must be used. This involves the analysis of the noise in eight frequency bands.

A comparison of the loudness of some common noises is shown in Table below:

Noise	Sones	Phons
Large jet plane 80m overhead	700	134
Heavy road traffic at kerbside	79	103
Light road traffic at kerbside	16	80
Normal speech (male) at 1 m	11	75
Inside noisy motor car	40	94

Table 3 - Loudness of common noises (Smith *et al*, 1996)

Definitions for units used to describe perception of noise

Phon: A unit of loudness level; the loudness level of a sound, in phons, is the sound pressure level of a 1000hz pure tone judged by the listener to be equally loud. An objective assessment can also be made using a microphone amplifier and a weighting network. The reference sound pressure level at 1kHz is $20\mu Nm^{-2}$.

Sone: A unit of loudness equal to a tone of 1kHz at a level of 40dB above the threshold of the listener; the sone is related to the phon scale as follows:

$$P = 40 + 10 \log_2 S$$

Where P=phons , S=sones

Noy:

A unit of perceived noisiness by which equal noisiness contours replace equal loudness contours. This unit of noisiness is related to the perceived noise level in PNdB by the formula:

$$\text{PNdB} = 40 + 10 \log_2 (\text{noy})’$$

Perhaps of more use when comparing noise and odour is the *Perceived Noise unit level* (PNdB). This is the sound pressure level of a band of noise from 910 to 1090Hz that sounds as noisy as the sound under comparison (see figure 14). This is conceptually very similar to the use of odour intensity units, where odour intensities are compared with the intensity scale of a reference odorant, such as n-butanol.

The 'noisiness' is given in *noys*. In effect, as the frequency increases, the perceived loudness of the sound is decreasing, even when the sound pressure in dB remains constant. Thus, 1 noy at 50 Hz will relate to 65dB, and at 2000 Hz will relate to approximately 32 dB. In effect, the change in frequency has effected a perceived change in sound pressure level. The proposed attribute of annoyance potential would offer a unit similar to the noy, which describes 'noisiness'. Such a unit for 'smelliness' would reflect the relationship between the pleasantness of an odour (as determined by for example hedonic tone) and the concentration. Hence, rather than basing assessments at a level of *n* odour units at the nearest receptor, *n* 'odour noys' could be substituted.

It should be noted, however, that such a refinement has not been introduced in noise regulations, where the issue is generally simplified, with noise being expressed in dB, by and large ignoring the cognitive aspects of noise appraisal or the distribution of sensitivity of individuals within a population. This approach is very similar, if not identical, to expressing odour exposure in terms of exposure to odour units, which has often been considered 'simplistic' by its critics.

Current legislation as outlined in the Noise at Work Regulations (1989) centres around the duration of exposure at a given sound pressure level, in dB or dB(A), in order to determine the personal daily noise exposure level ($L_{\mathrm{EP,d}}$). No account is taken of the other attributes, such as frequency. Hence annoyance potential is not considered in terms of overall sound pressure level, but rather in terms of 'loudness'. The physiological health effect of noise-induced hearing loss is, however, frequency dependent, with narrowband noise being far more serious than broadband noise. Therefore, the setting of these limits for such legislative guidelines has been undertaken on the basis of monitoring simplicity rather than health and safety implications. Similarly, current monitoring reof perception of odorants is usually related to frequency of exceeding odour concentration only, ignoring the nuisance that could be expressed in terms of annoyance potential.

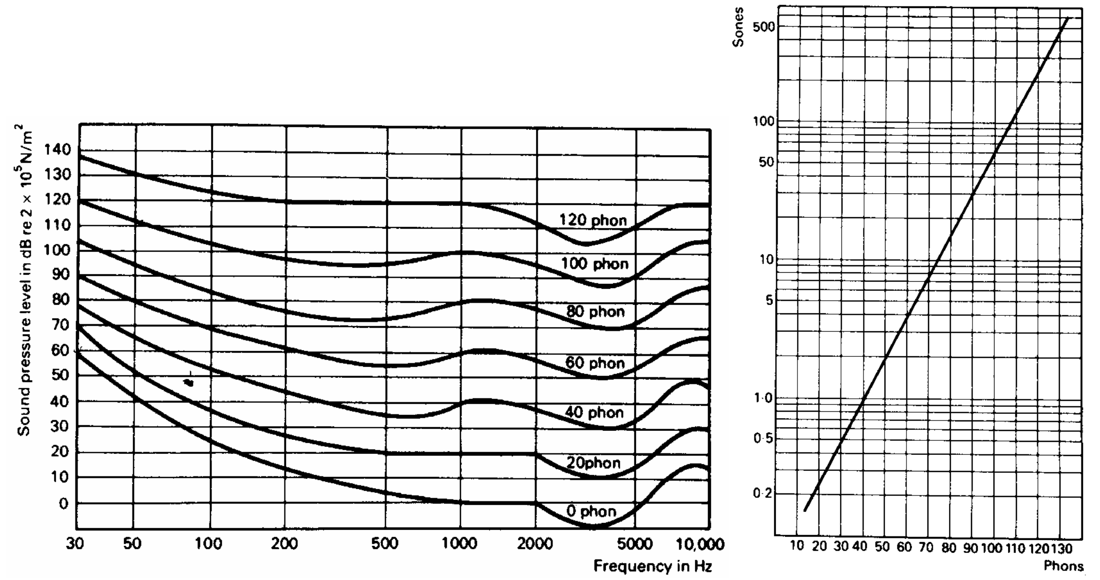


Figure 13 The relationship between dB, frequency and phons (left graph) and between phons and sones (right). Source: Smith et al, 1996.

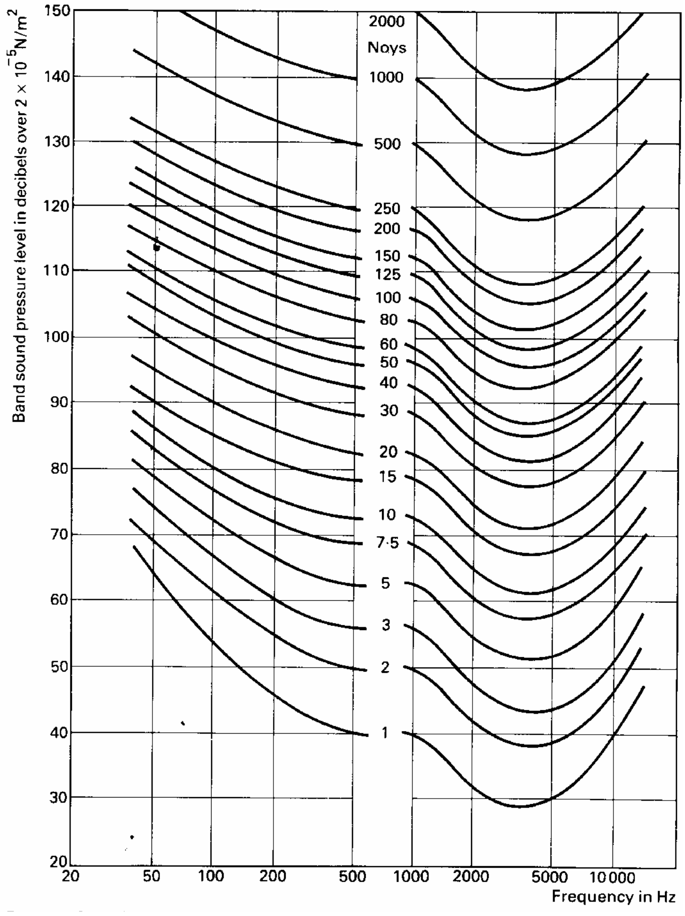


Figure 14 PNdB in relation to frequency

4.5 Common features of units for describing exposure to noise and odour: dB and dB$_{od}$

Our senses are equipped to respond to a wide range of stimuli. Our ears detect faint sounds, but can also cope with very loud noises: from a whisper to a roar. The response characteristics of our sense of smell are similar.

Human perception of the environment through vision, hearing, touch, smell and taste is characterized by a good discrimination of stimulus intensity differences and a decaying sensitivity to a continuous stimulus (Berglund, Lindvall, 1995).

The common concepts used in the description of noise and odour perception and cognitive appraisal haven been introduced in section 0. This section explores where, in a practical sense, convergence can be achieved in the methods used to describe exposure to environmental noise and odour, through identifying relevant similarities between well-known noise parameters and units used to characterise odours.

The stimulus for sound is variation in air pressure, in a certain range of frequencies. The energy that is transferred to the eardrum by these pressure variations determines the strength of the stimulus. This energy is measured in a linear unit, pressure (µPa) or energy (Watt per square meter, W/m^2).

As the range of magnitude of audible stimuli is very large, and powers of ten are not the most intuitive of measures, logarithmic measures are commonly used to describe these stimuli. The idea to describe a signal, or stimulus, in term of a logarithm of the proportion (or ratio) between the actual value and the detection threshold, is attributed to Alexander Graham Bell (1847-1922), the inventor of the telephone. He was interested in describing the strength of signals, and coined the unit: *bel*.

In mathematical terms: $L = \log(I/I_0)$

where I is the strength of the signal, and I_0 is the smallest detectable signal. As this measure is a bit coarse, the decibel is more common:

$$L = 10 \cdot \log(I/I_0)$$

The decibel is best known for describing noise levels. The reference value I_0 is a consensus value for the threshold of hearing at a frequency of 1000 Hz. This level has been established experimentally, in sensory experiments using young people as panel members. The exact description of the population sample is, however, not clearly defined.

The threshold of detection of hearing, at a frequency of 1000 Hz, is approximately 20 µPa. This stimulus is approximately equivalent to 10^{-12} W/m^2 when expressed in units of energy. The energy that is picked up by the human ear is an even smaller quantity. The eardrum has an approximate area of only 1 cm^2, or 10^{-4} m^2, hence the minimum energy uptake of 10^{-16} Watt by the eardrum will be the minimum stimulus for detection. This sound pressure at this level is 0 dB by definition.

Therefore $I_0 = 10^{-12}$ W/m^2 at 1000 Hz, and a stimulus of 10^{-12} W/m$^2 \equiv 0$ dB.

The loudest noise that we can perceive is close to the threshold of pain, or around 100 000 000 μPa. This stimulus is approximately equivalent to 10 W/m^2, or an energy uptake of 10^{-3} Watt by the eardrum. Such a noise is equivalent to 130 dB.
When the sound level is expressed as pressure, the Sound Pressure Level in dB can be calculated as follows: -

$$SPL = 20 \cdot \log({}^{p}\!/_{p_0})\ \mathrm{dB}$$

where

p is the root mean square sound pressure fluctuation in Nm^{-2} or Pa
p_0 is the root mean square reference pressure of $2 \cdot 10^{-5}$ Pa or its equivalent in Nm^{-2}

The same model can be applied to quantify odour stimuli (Oberthür, 1990). In the European standard EN13725 the threshold value, or zero odour decibel is defined as a consensus value equivalent to an odour of 40 ppb n-butanol. So, if 0 dB$_{od}$ ≡ 40 ppb n-butanol = 1 ou$_E$·m^{-3}, then odours can be expressed, just like noise, in decibels; dB$_{od}$.

For the reference odour, the mathematics work very well. For example, a stimulus of 4000 ppb = 4ppm n-butanol can be expressed in dB$_{od}$:

$$L = 10 \cdot \log({}^{4000}\!/_{40}) = 10 \cdot \log(10^2) = 20\ \ \mathrm{dB_{od}}$$

For other odours, the reference must be the detection threshold for the odorant or mixture under study. As the measurement of odour concentration involves determination of threshold, the application of the dB model is very suitable to describe odour stimuli in a simple, practical manner.

In the assessment of sound, the dB(A) filter has been introduced to reflect the differences in sensitivity of the human hearing to sound levels at different frequencies. Olfactory sensitivity, determined as a detection threshold, can be expressed as a mass concentration for a chemical. The olfactory sensitivity to compounds varies considerably from compound to compound, just as hearing varies from frequency to frequency. Therefore the dB$_{od}$ must always be expressed on the basis of the detection threshold *for that compound or mixture*. Conceptually, the choice of a particular odour is not dissimilar from defining a particular frequency for noise.

In summary: the strength, or intensity of both noise and smell can be defined by expressing the stimulus relative to the stimulus at detection threshold in a sample of people.
The anchor for the odour unit is the detection threshold, which has been defined using 40 ppb of reference odorant n-butanol, based on tests with human subjects. This detection threshold is described by 1 ou$_E$·m^{-3} which is equivalent to 0 dB$_{od}$.

For odour, the range between detection thresholds and unbearably strong smells is not as large as for sound, with the dB scale going up to 130 dB to reach the pain threshold, but still considerable. Odours at the high end of the intensity range (extremely strong) may contain hundreds of thousands or even millions of ou$_E$·m^{-3}. Therefore the range of odour intensities, in dB$_{od}$, is open ended, but relevant in environmental practice in the range of 0 to 60 dB$_{od}$.

Although the dB$_{od}$ has been proposed some time ago, and is also included in the draft standard EN13725:1999, it is not commonly used. When interpreting odour measurements it is, however, useful to realise that the odour concentration, ou$_E$·m^{-3} is a linear unit, just like the

W/m^2 for noise. The principal similarity between these units is that their relationship to perceived intensity cannot easily be interpreted intuitively. These linear parameters tend to reach very large values, making clumsy numbers for practical use.

By using dB units, similar to those used for noise, odour intensity can be associated with a more tangible unit, directly comparable to the decibel used in noise assessment. For example, a reduction in odour concentration by a filter with 90% efficiency amounts to a reduction with 10 dB_{od} while a filter performing at 99% abatement efficiency achieves a 20 dB_{od} reduction in odour intensity.

In this report the dB_{od} is proposed as the most practical unit to characterise odour exposure. This may seem odd at first, as odour assessment has typically been using linear units, such as the odour concentration in odour units ($ou_E \cdot m^{-3}$). It is, however, worthwhile to describe odours using a unit that is well known in describing exposure to noise, which is the sensory ambient stressor with an established regulatory framework.

4.5.1 Conclusions of comparisons between noise and odour assessment

As a conclusion it can be stated that some of the concepts applied in noise evaluation and legislation are similar, if not directly comparable, to odour evaluation. The comparison applies particularly to the assessment of statutory nuisance where no specific numerical limits are laid down for either pollutant. There are several areas where the concepts applied to these sensory stressors may be converged to some degree, as is proposed in section 0. However, there are fundamental differences, mainly because of the greater variety in sensitivity to the full range of odorants, as compared to the relatively simple and well-documented differences in response to the range of sound frequency. To improve approaches to characterisation of exposure and the understanding of mechanisms that lead to annoyance comparing research from noise and odour studies can be beneficial.

Characterisation of exposure to environmental noise by measuring sound pressure level in dB, referring to a simple consensus value for the detection threshold of hearing, is much easier and straightforward than measuring odour concentration. In odour measurement, after all, the actual odour threshold is determined with human assessors for the ambient odour in question. Assessment of exposure to complex noise is typically reduced to a measurement based on consensus regarding the reference value of human hearing. When it comes to characterising the perceived nature of the noise in more subtle and less practical terms of phons, sones and, importantly, noys, the relative simplicity of noise characterisation rapidly becomes less obvious.

It is important to note that available concepts, such as perceived loudness, variability in susceptibility to noise, the potential of a noise to cause annoyance ('noisiness' in noys) are largely not considered in the practice of noise regulations.

The use of the dB, especially as a L_{Aeq} does risk oversimplification of the evaluation. However it's use is backed up with numerous surveys and many years of experience in the acoustics field. Where odour regulations on the basis of limiting exposure measured in dB_{od} or odour units are sometimes criticised as 'crude and simplistic', a similar simplification in the use of dB for characterising exposure to all types of noise is widely accepted and rarely questioned.

Expressing odour exposure in terms of concentration units also risks oversimplification by ignoring annoyance potential and differences in perceived intensity at higher concentrations, as has been the practice in recent years. However, as in noise evaluation, even the simplified approach does contribute to a quantitative basis for assessing exposure to ambient odours.

5. METHODOLOGY FOR ESTABLISHING DOSE EFFECT RELATIONSHIPS FOR ODOUR INDUCED ANNOYANCE

This chapter introduces a conceptual model to describe the relationship between odour exposure and nuisance in terms of a statistical dose effect model (i.e. the relationship between odour exposure and the resulting degree of annoyance in an exposed population). A number of practical methods to describe the *effect* of exposure to odour as an environmental stress and assessment of the *dos*e using source characterisation techniques and dispersion modelling are discussed. A detailed discussion of the practical application of mathematical dispersion models is presented including identification of the key issues and scope for improving the prediction capability of these models.

To establish air quality criteria for odours, with a view to assuring that exposure of odours is limited to levels that are acceptable from a public health and well-being perspective, we need to establish a dose effect relationship describing the relationship between exposure to odours in the environment and the resulting degree of annoyance in the exposed population. This epidemiological basis is indispensable for setting environmental criteria in a quantitative framework.

5.1 Conceptual and mathematical model for prevalence of annoyance in a population

The relationship between exposure to odours (dose) and annoyance (effect) can be described by a mathematical function. To do so effectively, a conceptual model is applied to try and understand the relations, which are then fitted into a mathematical model for operational analysis.

5.1.1 Conceptual model of the relationship between odour exposure and nuisance

Exposure to odours is described by the exposure calculated from the emissions measured at source and the long-term meteorology for the location and topographical characteristics. These inputs are fed into an atmospheric dispersion model to calculate a suitable parameter, such as the C_{98}: the 98th percentile of 1-hour mean odour concentrations.

The effect is described as a percentage of people ‘annoyed’, as determined by a suitable survey method (see section 0). The numerical parameter describing ‘annoyance’ is the percentage of individuals in a sample within one exposure category that is classified as ‘annoyed’.

The frequency distribution for this relationship is assumed to be lognormal in a number of publications on such surveys (Verschut, 1991). This would imply that annoyance percentages, after transformation to z-scores, would show a linear relationship to the logarithms of exposure, expressed as C_{98}.

Reality is likely to be more complicated. Surveys into appraisal and coping behaviour have indicated that there are various types of behaviour within an exposed population. (Van der Linden e.a., 1989). This would indicate that, at similar levels of exposure, groups of individuals within the population will show markedly different types of behaviour, depending on their appraisal of the ambient stressor and the ‘coping strategy’ that is then assumed. Some individuals will take action and try and remove the stressor from their environment, by complaining, starting legal proceedings etc. Others will try and reduce the effects of the ambient stressor by attempting to modulate their own emotional response. In this way, again simplified, two types of behaviour can be identified in a population (type A and type B), each with its own *nuisance sensitivity*, dose effect relationship, and each with its own frequency distribution.

The proportion of Type A and Type B behaviour in a given population can differ: e.g. a quarter type A and three quarters type B. This would result in a bimodal frequency distribution for the effect in the population as a whole.
The effect is illustrated in the

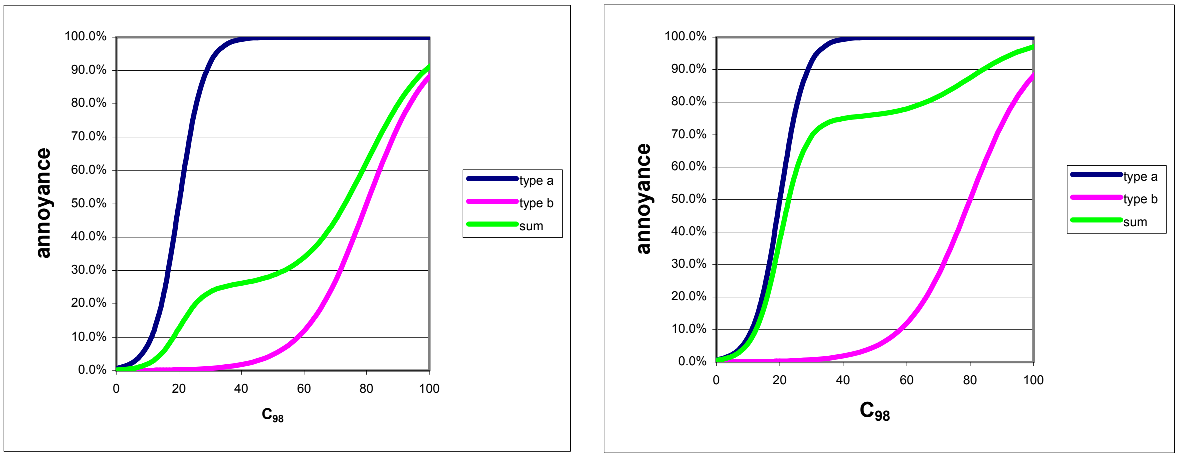


Figure 15 Mathematical model of the relationship between annoyance and exposure to odours, in a population consisting of two subgroups with different nuisance sensitivity (simulated data).

The frequency distributions in each of these figures are lognormal, in relation to exposure expressed as $C_{98,\ 1\text{-hour}}$. In the left figure, a quarter of the population is type A and three quarters type B. This leads to a combined behaviour as indicated by the green line, where a plateau level is reached. At increasing exposure levels the annoyance percentages will start to increase again, when group B kicks in. In the left figure, the mix is reversed, producing a different overall picture, with smoothly increasing annoyance percentages up to very high exposure levels, and then tailing off.

In practice, it is not feasible to experimentally determine the entire distribution. Fortunately, situations where annoyance levels reach 100% do not in reality occur. For policy related studies, the range between the ‘background level for nuisance’ and a significant nuisance level that would occur in real life situations is relevant, e.g. 3 to approx. 20% nuisance. It is within this range that an upper level of acceptable exposure can be set for regulatory purposes.

Taking this limited scope in consideration, the model used to describe the dose effect relationship can effectively assume one frequency distribution, in most cases. Only when the less nuisance sensitive Type B is present in a large majority, for example more than ¾ of the sample, will the bi-modal distribution will need to be considered. In all other cases, the relationship can be considered as single continuous frequency distribution.

5.1.2 Statistical model for the relationship between odour exposure and percentage nuisance

The mathematical model that was found to be most suitable to describe the dose effect relationship is logistical regression, as described in *Applied Logistic Regression Analysis* by Scott Menard (in Series: Quantitative Applications in the Social Sciences 106, 1995)

In mathematical terms, a logistical regression line is defined as follows:
$\text{Logit}(H) = \beta_0 + \beta_1 * \ln(C_{98})$

where:

$$H = \frac{\exp(\beta_0 + \beta_1 * \ln(C_{98}))}{1 + \exp(\beta_0 + \beta_1 * \ln(C_{98}))}$$

and:

H = the probability of nuisance (percentage/100).
β_0 = regression coefficient - intercept
β_1 = regression coefficient - slope
$\ln(C_{98})$ = the natural logarithm of odour exposure expressed as $C_{98,\ 1\text{-hour}}\ \text{ou}_E{\cdot}\text{m}^{-3}$

The formula can be graphically represented by an S-shaped curve as illustrated in the figure below. However, for reasons previously explained, we are only able to obtain experimental data for the lower 'tail' of the S shape, as illustrated in the graph on the right.

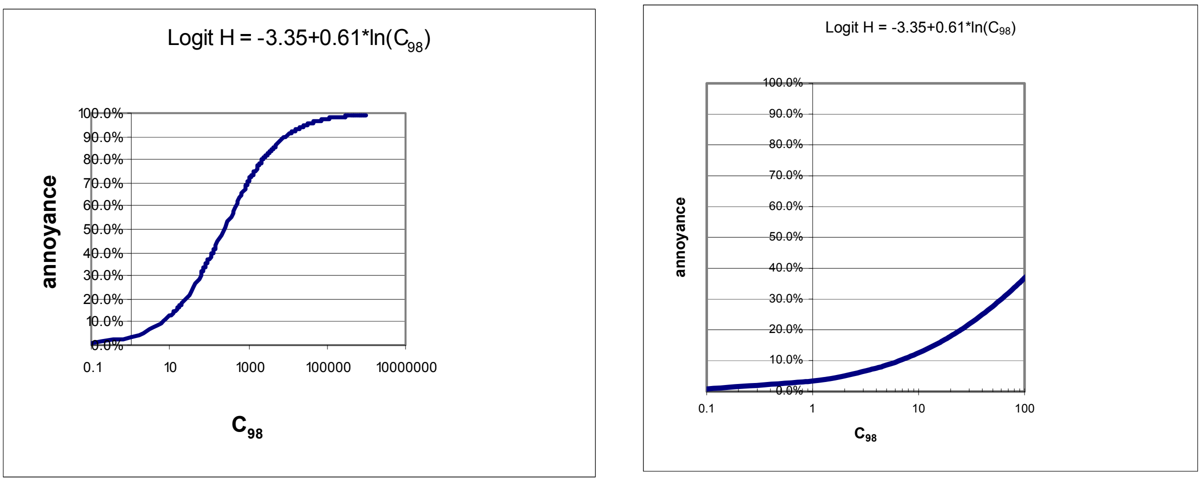


Figure 16 Theoretical mathematical model of the relationship between annoyance and exposure to odours, and the range in which experimental data can be collected in real world conditions, on the right (simulated data).

5.2 General methodology to describe the effect

An inherent problem in researching the relationship between exposure to odour as an ambient stressor and its effects on humans is that the physiological and behavioural effects are usually poorly defined. The outcome of methods to quantify the effect are inherently dependent on the methodology, to some degree. Typically, the method used to assess effect leads to classification of individuals who into those 'not annoyed' and those, 'annoyed'. In some cases a refinement is added, in the form of a category 'seriously annoyed'. The effect can then be expressed as the fraction (probability) or percentage of individuals that are affected in the sample that was considered in the survey.

The lack of definition of effect is important to note. It may represent:

- The probability that people will register a complaint
- The probability that people will reply that they are ‘annoyed’ or ‘seriously annoyed’ in a written questionnaire
- The probability that people will reply that they are ‘annoyed’ or ‘seriously annoyed’ in a telephone survey, using a questionnaire
- The probability that people indicate a value over a chosen criterion on a thermometer-like ‘annoyance scale’

As in all interviews, (or questionnaires) the answer obtained when assessing the specific definition of the effect depends on the way in which the question is asked. This leads to systematic differences in outcome, depending on the methodology and the actual list of questions used.

When reviewing results of studies into annoyance and nuisance, it is therefore highly relevant and crucial to take into account which measure was used to describe certain individuals as ‘annoyed’, distinguishing them from those ‘not annoyed’.

For this reason, it is necessary to describe the various methods to measure nuisance and annoyance in a sample of individuals. A detailed discussion is presented in the following paragraphs.

In reviewing the outcome of such relationships, and setting air quality criteria, it should be noted that it is not very helpful to tell individual people that they ‘can’t experience nuisance because the air quality criterion is met’. None of these methods describe individuals; they describe generalised behaviour in a population that has a considerable range of variation in its response to odours and the related cognitive appraisal and coping of odour as an ambient stressor.

Finally, the importance of regulatory experience on the basis of case history cannot be over emphasised. In the absence of an objective criterion for ‘acceptable annoyance’ the objectives of a society for its air quality in terms of odour must be set in the ongoing practical experience of that society. Objectives are best defined by reviewing a large number of cases, and where possible reviewing the outcome of regulatory processes by assessing if the outcome is a satisfactory balance between the interests of the operator of the source and those exposed to its odour. This experience can be transferred to other cases by measuring dose and effect relationships, and setting criteria on the basis of that knowledge in situations where a satisfactory balance was found. This knowledge can then be transferred to other specific situations, or used to predict the impact of proposed sources on Greenfield sites.

5.2.1 Continuous survey of percentage of people affected by nuisance: DLO

This method applies a questionnaire, covering a number of questions concerning the living environment. The questions concern all ambient stressors and other factors determining the perceived quality of the residential living environment. The Central Bureau of Statistics in the Netherlands (CBS) has carried out the survey on a continuous basis since 1974 (Kruize, e.a, 1998). Between 1974 and 1986 a survey was conducted once every three years. Since 1996 the survey is conducted on a continuous basis. The aim of the survey is to describe the relationship between objective and subjective characteristics of the residential living environment.

The DLO questionnaire contains questions on a range of issues related to the residential living environment, among which are questions on odour exposure and it's perceived impact. The questionnaire is used in face-to-face interviews at the residential address of the interviewed. Each month a sample of several hundreds of people is interviewed, covering all regions of the country.

The questions cover the following issues:

- The composition of the household, social and economical characteristics and residential characteristics;
- Quality of employment;
- Leisure activities and active participation in the community;
- Environmental attitudes, readiness to make sacrifices for environmental benefits, readiness to take action on environmental issues;
- Health and perceived well-being.

On the issue of odour nuisance, the following questions are posed to all participants:
I will now mention a number of factors that could cause nuisance in your residential environment. Can you indicate which of these, if any, are relevant to your residential environment? The factors are: traffic smells, smells from industries or business premises, rural smells, smells from open fires and/or stoves burning solid fuels.

Both the response *yes* and *sometimes* are classified as positive to determine the number of respondents that experience nuisance. The responses are entered into a computerized system, which screens on plausibility of answers. Only valid questionnaires are processed.

5.2.1.1 Capabilities of method

The Central Bureau of Statistics (CBS) of the Netherlands indicates that the expanded uncertainty of the measured percentage of the population experiencing nuisance is , $x\% \pm 3\%$, with a cover factor $k = 2$ (Kruize, e.a, 1998). The percentage for the Netherlands varies regionally. The percentage experiencing odour nuisance caused by industrial smells for 1994 had a national mean of 11% in 1994 (Kruize, e.a, 1998).

Long-term surveys such as the DLO are not particularly affected by incidents with high peak emissions of odours. Long term exposure because of fixed sources determine the outcome. The history of odour issues in a particular region can, however, be a significant factor determining the results (Walpot, 1991)

The results of these studies for 1985 to 1996 are presented in Figure 10, in section 0 (Kruize, H., 1998). They are also available on Internet site http://www.milieubalans.rivm.nl/themas/ind_4_8_vt_8000g.html.
The long-term study of CBS is the main indicator for the stated national objective of the Dutch government, that no more than 750 000 homes, or 12% of all homes/people should be experiencing nuisance (VROM, 1988).

5.2.2 Standardised Telephone Survey of the Living Environment: TLO

The Standardised Telephone Questionnaire (STQ) also known in literature by the Dutch acronym: TLO) is used to measure the percentage of people experiencing odour annoyance in a sample of the residential population, exposed to odours (Cavalini, 1992). The main application is to determine dose effect relationships, either in general or for a particular site.

The STQ is a population survey method that uses a standardised list of questions, which is an abbreviated version of the list used in the DLO survey (refer to section 0). Odour annoyance is only one of a range of issues covered by the questionnaire that is applied in telephone interviews. It is important that the interviewed individuals must not be aware that the survey is aimed specifically at odour to avoid bias. The abbreviated list is specifically aimed at odour annoyance, and optimised for use by telephone, which requires a limited list of questions so as to ensure cooperation of those that are interviewed.

The TLO is typically applied to sufficiently large samples of the exposed population, in at least four study areas, with different exposure levels. By collecting at least 100, preferably 200, TLO results for each exposure level test area, a dose effect relationship can be established.

There is no standard document with a protocol for this technique, although a unity of application exists in practice in the Netherlands, where the method has been applied relatively widely. A specific large scale dose effect study for pig production odours has been carried out there recently, and is an important contribution to the data underlying this report (Bongers e.a., 2001A, Bongers e.a., 2001B, see also section 0). The methodology requires specific expertise with survey methods to be applied successfully.

In practice, a STQ survey involves the following steps:
First, the area around the source or sources in question is surveyed. Ideally, the exposure experienced by the population should be the result of one source of odour only. Dispersion modelling is used to indicate exposure zones which are selected at suitable intervals, e.g.

- $0.5 < C_{98,\text{ 1-hour}} < 1.5\ ou_E \cdot m^{-3}$
- $1.5 \leq C_{98,\text{ 1-hour}} < 3.0\ ou_E \cdot m^{-3}$
- $3.0 \leq C_{98,\text{ 1-hour}} < 6.0\ ou_E \cdot m^{-3}$
- $6.0 \leq C_{98,\text{ 1-hour}} < 13\ ou_E \cdot m^{-3}$
- etc.

After delineating the test areas for each exposure category, all the addresses of residences with a telephone connection in the test area are listed. From this list, a random sample is drawn, typically of between 100 and 300 addresses. A letter is then sent to those in the sample announcing that a telephone survey will be held, aimed at assessing the quality of the living environment in the area. This has been found effective at increasing public participation in the survey. Shortly afterwards, all these addresses are called by telephone and, provided the person answering the phone is willing to cooperate, the questionnaire is presented. The questions relevant to odour are:

- Question: *I will now list a number of factors that can be annoying and may affect the quality of the living environment around your home. Can you tell me how often you have been affected in the past year by:* (choice from an itemised listing of annoyance factors)
- Question: *If you have been annoyed by any of these factors, I would like to ask to what degree you have been affected. Over the past year, have you been affected: hardly at all, moderately or seriously in terms of annoyance?*
- Question: *You just indicated that you experience annoyance by smells. Can you indicate the source of these smells?*

- Question*: Can you describe what type of company this is or what products they manufacture?*
- Question: *Can you briefly describe the odour in a couple of words?*

The STQ questionnaire is more focussed on the local conditions around the residence than the long term DLO questionnaire. In either questionnaires the questions are formulated in such a manner that it is not obvious that odour annoyance or annoyance in general is the main objective of the survey. The questions are aimed at characterising the subjective appraisal of the residential living environment of the individual in question. The method can be used in situations where the exposure is caused by multiple sources, although it will be more difficult to characterise exposure in multi-source situations.

Using the other questions in the questionnaire, or by adding specific questions or choice options, more specific information can be collected to characterise perceived environmental quality, population characteristics and the public perception of the sources in the area.

The cost of an STQ survey is in the order of £25 per questionnaire. Its application in specific licensing cases is limited, as in most cases the number of people exposed is insufficient to apply the method successfully. Direct measurement of annoyance is a valuable method to determine the underlying dose effect relationships, in carefully selected case studies.

The expanded uncertainty is estimated to be in the same order as that for the DLO: $x\% \pm 3\%$, with a cover factor $k = 2$

5.2.3 Measuring percentage of people experiencing nuisance using face-to-face interviews

This approach is very similar to the telephone survey, but is obviously different in the way the interview is conducted. The fundamental difference is that it allows the use of scales that are visual rather than usable with words only. An example of such a scale is the ‘nuisance thermometer (Winneke, 1987).

The result of the methodology can be expressed in a similar manner to the telephone survey, as a percentage of people ‘annoyed’. When comparing results of different methodologies, all leading to ‘% annoyed’, the potential for differences between the results because of methodological bias should be carefully considered.

5.2.4 Complaints analysis

Complaint analysis is not covered by any standard method or recognised protocol. Usually complaints are registered by local, regional or even national authorities or by companies who have a customer relations system that can be adapted for complaint registration.

Complaints registration provides an insight into the prevalence of a symptom of odour annoyance, not in the prevalence of the annoyance itself. There are many factors at play that determine the ease or difficulty of registering a complaint. Therefore complaint data must be interpreted with some caution. Registered complaints are a very strong indication that odour nuisance is a reality in a specific situation. However, the absence of registered complaints does not necessarily indicate the absence of nuisance. Also, once a conflict situation develops over emissions of odour, the registering of complaints can become a tool in the fight, when residents use orchestrated complaints as a political lever to move the argument in their favour.

The approach in setting up complaints registration and analysis must be determined and tailored to the purpose of the registration.

The minimum information that needs to be collected for each complaint is:

- Location (within approx. 100m, i.e. address complete with number) where the offensive odour occurred;
- Time when the offensive odour was observed;
- Characterisation of offensive odour, preferably on the basis of a choice from standardised descriptors;
- Preferably the identity of the complainant, to assess repeated nature of complaints;
- Residential address of complainant.

In complaint analysis, each complaint should be verified and collated with additional information:

- Wind direction, wind speed and stability class at the time of complaint;
- Any process incidents at the time of complaint.

The benefits of a complaints registration system can be greatly improved by implementing a standard protocol for complaint data registration and processing. Professional advice, including co-ordination with complaint registration units of the local authority or other organisations, is advisable.

A quick and adequate response to complainants is vital in those situations where community relations can be improved. This part of the complaints response process should be regarded as a fully-fledged method of annoyance reduction, as it can be very beneficial indeed to reduce anxiety in the complainant by adequate response and supply of information.

The results of complaint registration and response should be fully analysed periodically.

5.3 Methodology to describe exposure

Exposure to odours is typically characterised by measurement of emissions at source, using sampling methods followed by olfactometry, according to European draft standard EN13725 (1999).

When a proposed development on a Greenfield site needs to be assessed, emission factors from similar sources may be used, or emission factors established for a branch of industry.

When emission measurements are not possible, for example because the emissions are diffusive or highly complex, field panel measurements can be used, to determine the maximum distance at which the odour of the existing source can be detected. From this distance, and meteorological observations during the measurement, an estimated emission rate for the source can be established using a mathematical dispersion model (Van Broeck e.a., 2000, Van Broeck e.a. 2001).

Measurement of ambient odours through sampling is not a suitable method for assessing odour exposure. The most important reason is that the variability that is introduced by the weather is highly determining for the actual concentration found at one location, at one point in time. The difficulty in characterising the weather conditions adequately to describe dispersion conditions at a particular moment becomes extremely difficult at shorter sampling times, particularly times of less than one hour. A second fundamental problem with this approach is that the odour concentrations that occur in ambient conditions will generally not be high enough to be analysed reliably using olfactometry, which has a certain lower detection limit. Even methodologies or instrumentation suitable for low concentration measurements will typically not be able to reliably measure below 20 to 30 $ou_E \cdot m^{-3}$ because of background odours of sampling equipment, background odours in the dilution air and odour laboratory etc.

All successful emission characterisation methods in the end provide an emission rate in odour units per unit of time, which can be used as an input for dispersion modelling. Dispersion modelling is an essential tool in assessing odour exposure (see section 0 for details).

The end result of source characterisation and modelling is a map describing odour exposure, providing contours enclosing areas where a certain exposure is exceeded with a particular frequency (percentile value). The methodology for characterising emissions at source and assessing the odour impact using dispersion modelling is described in the following sections.

5.4 Source characterisation

5.4.1 Sampling and measurement at source

This section describes the practical methods used to assess odour emissions at source. Although it is preferable to determine the odour emissions from specific sources, and hence enable any site-specific factors to be assessed, in some cases it may be necessary to use available emission factors to estimate emissions (e.g. for Greenfield sites or predicting future improvements resulting form a particular cause of remedial action etc).

Sampling must be carried out in accordance with the CEN standard prEN13725. Samples are collected in odour sampling bags made out of a suitably odour free material, such as Nalophane. Odour samples must be analysed as quickly as possible, but no later than 30 hours after sample collection. When sampling odours, it is important to consider any Health and Safety issues which may impact on the procedures adopted.

5.4.1.1 Point sources

The methodology for sampling of point sources is described in CEN standard prEN13725.

If a risk of condensation of the odour sample in the bag exists or when concentrations are expected to be higher than the measuring range of the olfactometer to be used, dynamic pre-dilution on site may be required.

5.4.1.2 Area sources

Area sources must be sampled in accordance with the general principles of CEN standard prEN13725.

To establish specific emission rates from liquid and solid surfaces a sampling hood is the preferred method. Other methods for assessment of emissions from liquid and solid sources are available and should be tailored to the specific requirements of the source.

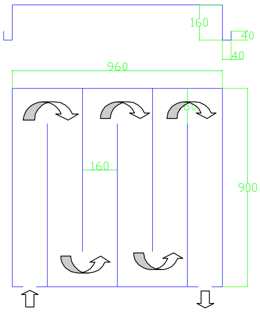


Figure 17 Example of Lindvall sampling hood for area sources

In using the sampling hood method, the choice of the correct parameters of operation is of vital importance. The sampling hood must use a flow velocity under the hood of 0.2-0.3 m/s and have a headspace height of no more than 200 mm. The path length must be sufficient to allow the concentration under the hood to reach values that can be readily measured using olfactometry.

Generally speaking olfactometry becomes more difficult at concentrations below 50 $ou_E{\cdot}m^{-3}$ because of background odours in sample bags etc.

As an example a Lindvall type sampling hood of suitable dimensions is pictured in Figure 17. The section of the headspace is 160 × 160 mm with a total path length of 6 × 960= 5760mm. The 'hood constant' *L* can be calculated as:

$$L = \frac{\text{flow path section } [\mathrm{m}^2]}{\text{covered area } [\mathrm{m}^2]}$$

Once the hood factor *L* is known, the specific emission rate can be calculated from the concentration measured at the exit of the hood and the flow velocity *V*:

$$E_{sp} = C_{hood} \times L \times V$$

In our example the hood factor *L* is 0.027778, and the flow velocity $V = 0.25$ m/s, which implies that at a specific emission rate of 1 $ou_E/m^2/s$, an odour concentration of 144 ou_E/m^3 is measured at the exit of the hood.

This implies that emission rates as low as approximately 0.5 $ou_E/m^2/s$ can be measured without coming too close to the lower detection limit of the method of the odour concentration measurement (approximately 50 ou_E/m^3).

5.4.1.3 Odour concentration analysis

Odour samples should be analysed in compliance with the draft standard EN13725 'Odour concentration measurement by 'dynamic olfactometry'. (refer to section 0).

5.4.2 Field panels, short term evaluations

Field panel measurements provide an estimate of total emissions from a source, including all diffuse sources (Van Broeck e.a., 2000).

Field panels consist of 4-6 trained, qualified panel members selected using the same criteria as used for the odour laboratory, according to prEN13725. The field panel makes observations on locations in the field, usually to determine the maximum distance of detectability of the odour from a particular source. This result, combined with the meteorological conditions during the field observations, is used for 'reverse dispersion modelling', which gives an estimated source emission rate as a result. Field panels can also be used to provide information on odour intensity and/or hedonic tone in field conditions.

A practical test procedure is described here. At any given location the panel makes observations every 10 seconds, for a duration of up to ten minutes. By traversing the 'plume' at intersections at varying distances, the results are gathered in the course of a number of hours. The technique has been applied for a number of years, in some countries, in applied odour research. An unofficial guideline for carrying out these measurements has been published in the Netherlands (Anzion *et al*, 1994), while in Germany a guideline has been published: VDI3940:1993.

The panel can not only be used for evaluating detectability of the source as a whole but it can also be used as a more ‘analytical’ instrument by teaching the panel to identify specific smells on-site and using this perceptive expertise to identify individual sources downwind. Using this technique the following information is recorded: type of smell, intensity and relative annoyance potential to the overall off site smell. This provides useful qualitative data, although they cannot lead to decisive conclusions as they reflect an assessment by a limited sample of the population, only briefly exposed to these odours.

The field panel work requires certain weather conditions and requires characterisation of meteorological conditions during measurements (wind speed, wind direction and stability class).

The inherent uncertainty of the method of measurement is mainly determined by the inaccuracies involved in characterising the turbulence in the mixing layer of the atmosphere, and the relatively poor capabilities of models to accurately predict short-term downwind concentrations. Generally speaking, the results of modelling impact on the basis of source emission data will give a more reliable result. Field panel data can, however, be invaluable in providing a field check based on actual conditions, especially where sources are complex and include diffuse sources (i.e. natural ventilation, large area sources etc).

5.4.3 Field panels, long term evaluations

In 1994 an odour regulation for industrial sources on the basis of long-term field observations was introduced in the state Nordrheinland-Westfalen: Geruchs Immissions Richtlinie (GIRL, 1994). This guideline is based on measuring the actual frequency at which odours can be perceived in the vicinity of the source in question, over a period of 6 to 12 months.

A number of fixed observation points are determined, on a regular grid, access allowing. A number of observers are assigned to the task of making observations at these points, according to a pre-determined schedule. The assessor makes observations at ten second intervals, over a 10-minute period. The number of observations with a positive detection is divided by the total number of observations in the 10-minute period, and a percentage of positive observation is calculated. If the percentage is above a limit value, typically 10%, the measurement at that point in that 10-minute interval is considered to be an ‘odour hour’. The frequency of ‘odour hours’ is used as the criterion to determine if a ‘relevant nuisance’ exists at that grid point. The limit value for residential areas is 10%, while for trade and industrial zones a more lenient 15% limit is applied.

The method requires approx. 26 measurements, on different days, for each point, while allowing no more than 5 of these measurements to be done by the same assessor. The requirements for human resources are therefore considerable.

The methodology is described in the guideline VDI3940:1993 and in the GIRL.

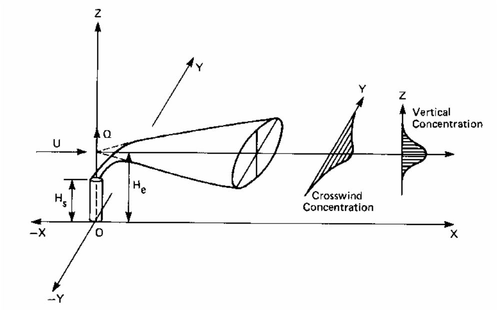
The long-term field panel method is useful, in that its methodology and approach are easily envisaged, and understandable. The considerable resources and cost involved are limiting factors in its practical application. Concerns have been raised about the statistical basis of the experimental design, when the assessment programme is in any way limited because of practical and/or cost implications.

5.5 Dispersion modelling using source emission data

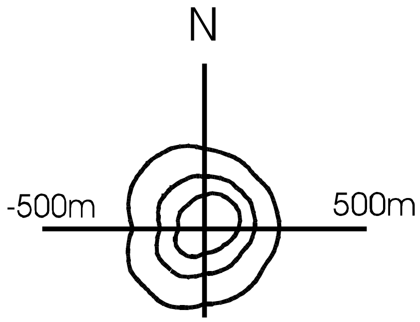
Once the odour emission rate from the source is known, in $ou_E \cdot s^{-1}$, the impact in the vicinity can be estimated. The impact of an emission is very strongly determined by the way in which the odour is diluted in the atmosphere, while being carried towards the receptor by the wind. The dilution can vary considerably, depending on the meteorological conditions: wind speed and turbulence of the atmosphere, also called atmospheric stability. The meteorology of a site will be a major factor determining the impact of a certain release of odours. To predict the impact as well as we can, computerised mathematical models for atmospheric dispersion models are used.

Atmospheric dispersion models

Most dispersion models are Gaussian models, which assume the concentration profile across the plume to follow a Gaussian probability curve.



The expansion of the plume is modelled by mathematically representing the standard deviation as a function of distance to source, wind speed, and atmospheric stability (turbulence). By repeated calculation of each receptor point in the study area, for each hour of the weather data set, a frequency distribution of hourly concentrations at that receptor point can be obtained. This distribution can be characterised by the concentration that is exceeded only 2% of time, in terms of hourly average concentrations. This is commonly called the 98-percentile. By drawing a line on the map connecting all points with the same concentration at the 98-percentile, for example at 5 $ou_E \cdot m^{-3}$, an odour contour line can be shown on a map. In the area enclosed by the contour the exposure level 5 $ou_E \cdot m^{-3}$ as a 98 percentile of hourly averages will be exceeded. Outside the contour the exposure will be less than the given criterion.



5.5.1 Characteristics of suitable atmospheric dispersion models

Dispersion models are used for predicting odour exposure with a view to assess expected annoyance. The relationship between odour exposure and annoyance has been established in a number of epidemiological studies, where a particular modelling approach was used. Ideally, *when using dispersion models for odour annoyance prediction, the objective must be to apply the models that were used to establish dose-effect relationships in the underlying epidemiological case studies.* This implies that, although better atmospheric dispersion models may become available, these can only be applied to odour problems *after* their results have been validated in dose effect studies, or by using base data from previous dose effect studies to establish the relationship between the model output and the annoyance criterion. The specific characteristics of the site in question and surrounding locality should also be carefully considered (e.g. incorporation of building effects, topography etc) in determining the most appropriate model to use for a particular study.

The relationship between modelled odour exposure and actual annoyance levels have been established using models and data with the following characteristics:

- Models were Gaussian plume models;

- To represent conditions for an ‘average year’ hourly meteorological data for a period of at least three, preferably five years were used;
- Models were used to calculate one-hour average concentrations for all hours in the meteorological dataset;
- Exposure was expressed as the concentration corresponding with a certain percentile of the distribution of hourly values, usually the 98-percentile

A commonly used model is the Industrial Source Complex (ISC) model developed by the US Environmental Protection Agency and used as a regulatory tool for atmospheric emissions in many parts of the world. ISC is a Gaussian dispersion model, which uses input data such as wind speed, wind direction, atmospheric stability and height of the mixing layer to determine ground level concentrations at defined receptor points.

In establishing odour exposure with a view to assessing the risk of odour annoyance, similar models must be used to those that were applied to derive the dose-effect relationship underpinning the exposure criteria that are applied in the assessment. Models that produce results that do not closely resemble those commonly applied to odour problems *must be validated for that application* before they can be used.

For practical purposes, other Gaussian models that are able to predict the frequency of one-hour average concentrations have been used.

The results are presented as contour lines for specific frequencies of occurrence of odour concentration with hourly average values above a certain limit value (air quality criterion).

5.5.2 Scope for improvements in prediction of odour annoyance by the use of shorter averaging times.

The perception of odours is very quick. One breath inhalation takes approx. 3 seconds. One inhalation can lead to odour detection, perception and appraisal. As we spend roughly half of our time exhaling, a practical value for the smallest period of interest to assessing the effects of odours is therefore approx. 5 seconds.

In predicting exposure, we typically use dispersion models. These models have been designed and found effective in predicting annual, monthly and daily averages of predicted concentrations. The smallest typical time-‘byte’ of calculation is typically one hour, as this is the common smallest timeframe over which meteorological data are recorded. Models have been found reasonably reliable in predicting the frequency of occurrence of concentrations over a long period of time, even at high percentile values, e.g. the 98th-percentile. The capability of a model to predict concentrations during one particular hour is less favourable, mainly because it is very difficult to obtain a good estimate of the turbulence of the mixing layer within that timeframe. Traditionally, discrete scales for ‘stability’ have been used, such as the Pasquill stability class, based on estimates of cloud cover. More recently, a more reliable continuous parameter has been developed, the Monin-Obukhov length, based on the incoming solar radiation energy.

What happens within one hour is a matter that has prompted a range of opinions in odour assessment discussions. In many cases, so-called peak-to-mean factors have been applied to proposed air quality criteria that were based on epidemiological dose effect studies, that typically used 98th-percentiles of one-hour average predictions to estimate exposure.

The objective of using peak to mean ratios to estimate short averaging times (down to 1 second) is to improve the experimental relationship between surveyed levels of annoyance (effect) and predicted exposure (dose). To the knowledge of the authors this improved prediction of annoyance levels from shorter average time dispersion modelling has not been demonstrated on any experimental data. It is therefore not at all clear yet whether application of peak to mean ratios can improve the prediction of annoyance.

Until validated studies on improvement of prediction of annoyance through application of peak to mean ratio's is available, their use in environmental impact assessment is not advisable.

5.5.3 Prospects for determining peak to mean ratios for practical application

The simple fact is that we lack data, both meteorological data and downwind concentration data, to assess and validate dispersion models at the 5-second interval level, that is the minimum relevant interval for odour perception.

However, it *is* known that the peaks, the height of peaks and the frequency of occurrence of peaks are determining for the perception of the odour.

From a simulation of data we can see that the issue is not so simple.

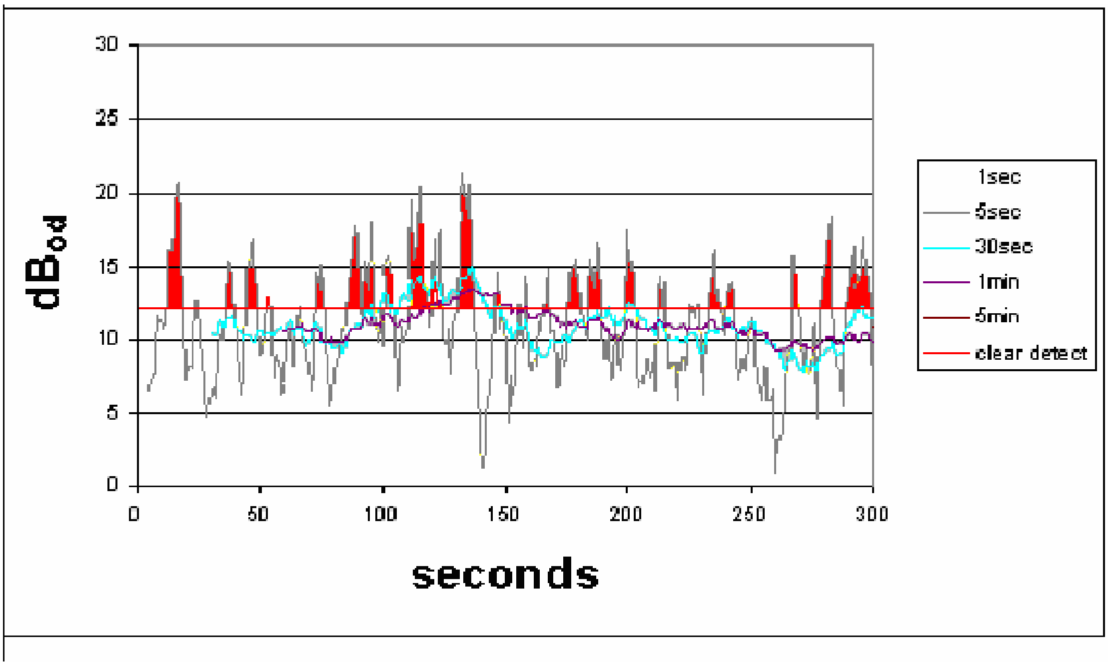


Figure 18 Simulated 1-second average concentration data, normally distributed, with 5 sec, 30 sec and 5 min running averages. Peaks for 1s data above 'clearly detectable' concentration are filled in red.

In the figure, a basic data set of one-second average concentrations was generated, with a normal frequency distribution and a plausible standard deviation. The lines fro 5 sec, 30 sec, 1 min, 5 min intervals was calculated as a running average at the appropriate time.

From the simulation in the figure it can be observed that the peak to mean ratio increases sharply with reduction of the interval. The peaks of the 5 sec line that are above a clearly detectable perceived intensity have been filled in with red. Although this is a simulation, the figure provides an insight in the issues at hand, even if it simplifies the real issues at hand. To account for the peaks, various 'peak-to-mean' ratios have been proposed and applied.

Generally such values are proposed as a generally applicable value, not differentiated for factors that have been suggested as having a significant influence on the peak-to-mean ratio, such as:

- Stability/turbulence of the mixing layer
- Type of source (point or area source)
- Distance to source
- Height of source above ground level

There are indications that such factors need to be taken into account in a practical application of peak to mean factors in dispersion modelling (Best, 1998).

Some models (Ausplume, ISC3) include an equation for the calculation of peak-to-mean ratios:

$$c_p = c_m \times A \times \left({t_m}/{t_p} \right)^p$$

where

c_p = short averaging time concentration

c_m = long averaging time concentration

t_p = short averaging time (order : minutes)

t_m = long averaging time (order : hours)

A = constant, close to 1

p = coefficient between 0.07 (unstable) to 0.35 (stable)

From US-EPA data (Thompson, 2000) based on a comparison of monitoring results of their nationwide network for SO2, a comparison can be made between maximum 5 minute average values and the corresponding 1-hour average results. The resulting peak-to-mean ratios, for a very large data set, are listed below:

Midpoint peak to mean ratio	frequency	cum. Freq.	% frequency	cum % freq
1.22	447422	447422	38.93	38.93
1.49	304840	752262	26.52	65.46
2.23	228065	980327	19.84	85.3
2.72	99553	1079880	8.66	93.96
4.48	54334	1134214	4.73	98.69
7.39	15052	1149266	1.31	100

Table 4 Peak to mean ratios for actual ambient air concentrations, 5-minute average values for SO_2, US EPA. (Thompson, 2000)

These data reflect all causes of variation, including mixing layer stability, source type and height, distance to source etc.

The equation from Ausplume, mentioned above, would predict values between 1.2 and 2.4 depending on stability class. These predicted values obviously fall well within the range and cover 85% of the observed values. However, in the remaining 15% of events, the peak to mean ratios would appear to be significantly higher. As we know that in odour issues, we need to focus on the few percent of worst cases to predict annoyance, the lack of accurate and validated prediction methods of peak to mean factors is a matter of concern.

In the technical notes accompanying a recent draft odour guideline of the New South Wales EPA (NSW-EPA, 2001) the estimation of peak-to-mean ratios has been included in the dispersion modelling guideline, based on specific research (Best, 1995, 1998).

The approach gives peak to mean ratio's to estimate the height of peaks, occurring at a probability of 10^{-3}, depending on a number of variables:

1) **Source type:**
   a) Area source
   b) Line source
   A line source becomes an area source if the breadth exceeds 20% of the length.
   c) Point source, ground level
   A point source requires fairly equal lateral dimensions that are very small compared to the distance to the nearest receptor.
   d) Point source, tall, wake free
   Tall wake-free stack sources extend over 30 m above the ground and are not likely to suffer aerodynamic downwash.
   e) Point source, tall, wake affected
   Wake-affected stack sources have a release height less than a factor of 2 below the height of the nearest building (i.e. a building located within 10 stack heights).

2) **Distance** (depending on atmospheric conditions)**:**
   a) Near field
   The zone where source structure directly affects plume dispersion and structure. The near field is typically 10 times the largest source dimension, either height or width.
   b) Mid field
   c) Far field
   The zone where plume rise and meandering have fully occurred and the plume is well mixed in the vertical plane from ground level to the base of the first temperature inversion. In the far field any mathematical expressions for the intensity, i(x), for different surface source characteristics should become similar.

3) **Stability class (Pasquill-Gifford)**
   a) D
   b) E, F
   c) A,B,C

These input variables can have a major impact on the frequency distribution of concentration.

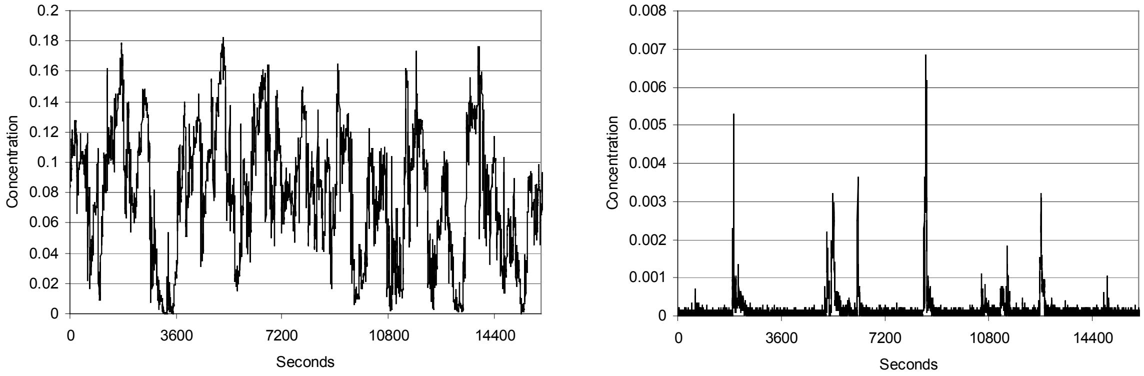


Figure 19 Concentration time-series from wind tunnel simulations of an area source (left) and an) elevated point source (right), for 1000 m downwind of the source in neutral stability. Source: (Best, P., 2001).

Based on the input variables listed above, values for the peak to mean ratio have been estimated, on the basis of experimental wind tunnel data and mathematical considerations. The results are presented in Table .

This tables shows recommended factors for estimating peak concentrations for different source types, stabilities and distances, for use in screening procedures for flat terrain situations.

Source type	Pasquill-Gifford stability class	Near field i_{max}	Near field x_{max}	Near field P/M60	Far field I	Far field P/M60
Area	D	0.5	500 to 1000	2.5	0.4	2.3
	E,F	0.5	300 to 800	2.3	0.3	1.9
	A,B,C	0.5	500 to 1000	2.5	0.4	2.3
Line	D	1	350	6	0.75	6
	E,F	1	250	6	0.65	6
	A,B,C	1	350	6	0.75	6
Point, surface	D	2.5	200	25	1.2	5 to 7
	E,F	2.5	200	25	1.2	5 to 7
	A,B,C	2	1000	12	0.6	3 to 4
Point, tall, wake-free	D	4.5	5 x height	35	1	6
	E,F	4.5	5 x height	35	1	6
	A,B,C	2.3	2.5 x height	17	0.5	3
Point, wake affected	A to F	0.4		2.3	0.4	2.3
Volume	A to F	0.4		2.3	0.4	2.3

i_{max} maximum centreline intensity of concentration.

x_{max} approximate location of imax in metres.

P/M60 Peak to mean ratio for long averaging times (typically 1 hour), at a probability of 10^{-3}

Default values are given for area and line sources in convective conditions, tall wake-free point sources in stable conditions,
wake-affected sources in convective conditions and volume sources in all stabilities. These values may be updated as more
Information becomes available.

Table 5 Factors for estimating peak concentrations in flat terrain (Source: NSW-EPA, 2001).

From the peak to mean ratios presented, with the caution that the values may be updated as more information becomes available, it can be concluded that the values vary considerably, from 1.9 to 35, depending on a the independent variables that were identified. This clearly demonstrates that the use of one blanket one-value-fits-all peak to mean ratio is not a satisfactory approach.

Additional variables are identified in the Australian work:
When more information becomes available, it will be possible to determine the dependence of i(x) on dimensionless ratios such as:

- *plume travel time to boundary layer time scale*
- *source size to boundary layer horizontal length scale*
- *source height to observer height*
- *source height to boundary layer depth*
- *crosswind distance to time-averaged plume width.*

This information is unlikely to be available for several years.

Although the Australian work contributes significantly to our understanding and operational tools for understanding and estimating the magnitude of short peaks within the hourly average, it provides only a starting point for actual application in odour annoyance prediction.

First, it will need to be demonstrated that the application of peak to mean ratio's improves our understanding of the mechanism that leads to annoyance, by improving the predicted level of annoyance in a population in dose effect studies, through application of peak to mean estimation.

A review of the existing epidemiological data would be required, reviewing the correlations found, using the new peak-to-mean estimation method. If the more advanced method to estimate exposure (dose) than that should become visible as a better prediction of annoyance (effect). Such a validation by returning to the base dose-effect data is essential to resolving the discussion on the use of peak to mean ratios.

Further exploration, investigation and validation of peak to mean ratio's is required before they can be applied to obtain improved annoyance estimates. Until that has been achieved, the relationship between a percentile of hourly averages and surveyed annoyance in epidemiological studies remain the best basis for any odour criterion.

Insights in peak to mean ratio's can, until that time, be used as a 'soft' risk factor in the conceptual model presented in section 0.

5.5.4 On the choice of meteorological data

For modelling purposes suitable meteorological data are required, consisting of 8760 hourly observations per year for the following parameters:

1) Wind speed
2) Wind direction
3) Atmospheric stability, which can be:
    a) Pasquill stability class (derived from cloud cover observation)
    b) Monin-Obukov length (derived from measurement of incoming solar energy)

To avoid error because of year-to-year variations, a minimum of five consecutive years data are required if these are available for a given location.

Data should be obtained for the 'most representative' meteorological station. This may not always be the closest station, especially where the issue of coastal versus inland locations is relevant. Specialist advice can be obtained from the Met Office. In some circumstances, wind speed and direction data may be available from a source closer to the site in question. In this cases it may be possible to combine this data with stability data from the nearest meteorological station, to establish a more representative assessment.

Meteorological data from individual stations are available from a number of suppliers at a budget cost of approximately 1200 Euro for 3-5 years data. The data have to be formatted so that they are suitable for use by the software of the chosen dispersion model.
It must be noted that coastal stations are usually not suitable for characterisation of more inland locations, even when the distance to the coastal station may be less than the distance to an inland station.

A more in-depth comparative analysis of differences between the dispersion patterns of different meteorological stations with a view to odour impact assessment would be advisable in the course of formulating a regulatory odour guideline.

5.5.5 On the choice of percentile values

In setting exposure criteria different percentiles can be used. However, these percentiles all reflect one distribution of values, determined by the meteorology at the location in question. Therefore, there is a relationship between a certain limit value at the 98th -percentile, at the 99th -percentile and at the 99.5th percentile based on the complex of underlying physical processes.

The relationship between the higher percentiles will be determined by the entire set of observations, provided that all underlying data are correct, or that a very large proportion are correct and that the frequency distribution is based on a curve fitting procedure, rather than counting values for individual hours. If counts of results for individual hours are used, anomalies may occur at the extremes of the distribution due to anomalies in a small proportion of the data (equipment failure, transcription errors etc) After all, the concentration at the 99.5th percentile, $C_{99.5}$ is based on a count of the ‘worst’ 44 hours in a year. Most models do not use curve fitting over the distribution, but sort and count the values of individual hours to arrive at percentile concentration results.

In choosing a suitable percentile to reflect a certain exposure level, both fundamental and practical issues must be considered. A fundamental issue is that for characterising exposure conditions that are determining odour annoyance, the relatively rare times with high exposure are more determining than the majority of time when the exposure is average or below average. This is a result of the exponential relationship between concentration and perceived intensity (see section 0) and the psychophysical and psychological processes involved. A practical issue is that the uncertainty of the prediction of the model is becoming greater at very high percentiles. The mean of the distribution has a smaller margin of error than the ‘tails’ of the distribution. At the high end of the percentiles, the outcome becomes increasingly vulnerable to anomalies that might significantly bias such a small fraction of hourly meteorological observations, because of unusual conditions and transitions or unrecognised anomalies in observation results.

In this report the 98th -percentile is used to set criteria, because this value can be seen as a compromise: it reflects the upper ‘tail’ of the distribution, but is based on the top 175 hourly observations in a year. To make this value more representative, a minimum of three years meteorological data is used, or 3 x 175 = 525 hours in total.

The relationship between the 99th -percentile and the 98th -percentile, in the conditions that prevail in the United Kingdom, is roughly:

$$C_{99,\ \text{1-hour}} \approx 2 \times C_{98}$$

In other words, a criterion of $C_{98,\ \text{1-hour}} < 6\ ou_E \cdot m^{-3}$ is approximately equivalent to $C_{99} < 13\ ou_E \cdot m^{-3}$. Please note that this is not a general relationship, but merely based on the observation that, for conditions in the UK, the frequency distribution is such that this rule of thumb applies.

6. OVERVIEW OF DOSE-EFFECT STUDIES FOR ODOUR INDUCED ANNOYANCE

In this section the relationship between calculated exposure to odours (dose) and percentage of the population experiencing annoyance (effect) is discussed on the basis of epidemiological studies. The studies that are available in the public domain were conducted mainly in the Netherlands and Germany. Such epidemiological studies must be the starting point for any criteria for odour exposure, with the objective of reducing annoyance to an acceptable level. The available epidemiological studies are reviewed. An argument is put forward for using 10% annoyance in a population as an operational value that indicates a behavioural effect of odour exposure with high probability, and hence could be used as a starting point for setting an environmental target for annoyance and, consequently, exposure. Finally, a discussion is provided of exposure levels derived from the available studies in so far as they are relevant for identifying an upper limit to 'acceptable' odour exposure.

The relationship between exposure to environmental odours impacting on a human resident population as an ambient stressor (dose) and potentially causing the effect of odour annoyance (effect) can be established using epidemiological studies (Winneke, 1987, Punter e.a., 1989, Verschut, 1991). Epidemiological data on the dose-effect relationship are an essential starting point for setting any quantitative environmental quality criterion. This is as valid for odour nuisance as it is for other air pollutants and ambient stressors such as noise.

It is surprising to see how many air quality criteria have been proposed in various states and regions worldwide without giving adequate consideration to the (lack of) available epidemiological data. Most epidemiological dose-effect studies for odour annoyance have been carried out in the Netherlands and in Germany. Studies that are in the public domain will be reviewed in this chapter, in the absence of suitable data collected for UK situations.

Some indicative data for the relationship between incidence of *complaints* and odour exposure for specific sources are available for the UK (see section 0). However, the incidence of complaints, as a symptom of odour annoyance, is not a reliable indicator for the level of annoyance. The availability of suitable complaint registration channels and other confounding factors may lead to an underestimation of annoyance levels, when these are determined by the incidence of complaints only and not verified by a systematic survey method to determine the prevalence of annoyance.

In Germany dose-effect studies are ongoing in research related to the introduction of the regulation 'Directive on Odour' in Nordrheinland Westfalen (Both, 2001). In these studies, the dose is determined in the percentage of 'odour hours' on the basis of actual field observations of the frequency of detection of odours in ambient air, using direct field panel observations on a grid of defined locations over a period of 6 months, see also section 0 (Sucker e.a., 2001, VDI3940, 1993). The level of annoyance is determined using an 'annoyance thermometer'. This is a graphical representation of a thermometer with an 11-point scale (0 to 10), where only the minimum and the maximum point are marked as *no disturbance at all* to *unbearably disturbed* respectively (VDI3883, 1997). Respondents in the survey are asked to mark their annoyance level on the thermometer in response to the question: '*To what extent are you disturbed by environmental odours?*' This scale has been used in many studies, both for noise and odour and can also be used in laboratory exposure studies. It has been compared to responses to a seven point annoyance scale where the points are characterised by words, from *not annoyed* to '*extremely annoyed'*. The outcome of these two scaling methods are compared to check consistency of application of these scales by the surveyed subjects (Sucker e.a., 2001). The global evaluation of the environmental situation, as far as odours are concerned, is established by asking whether ‘other residents consider the degree of odour annoyance acceptable or not’.

From several studies using this technique it would appear that the ‘critical segment’ of the annoyance thermometer, where exposure starts to show a clear effect, is associated with an increase from scale point 3 to scale point 4, where the percentage of subjects indicating ‘unacceptable’ increases from 10% to 20% (Sucker e.a., 2001). In areas unaffected by odour exposure, the mean response value using the annoyance thermometer is 1.5 (Winneke e.a., 1990). The relationship between the position on the ‘annoyance thermometer’ scale and the percentage indication a global judgement ‘unacceptable’ in response to a questionnaire question is shown in Figure 20. The increase of ‘intolerability’ of noise exposure as a function of the indicated value on the ‘annoyance thermometer’ is more gentle than for odours. The graph suggests that an odour with a relatively low ‘annoyance’ scale reading on the thermometer produces a higher score in terms of ‘intolerability’ (or perceived community impact) than noise. The research that aims to clarify the relationship between these different measures of ‘annoyance’ and validate the German odour exposure guideline is ongoing and is expected to be concluded in 2002 (Sucker e.a., 2001).

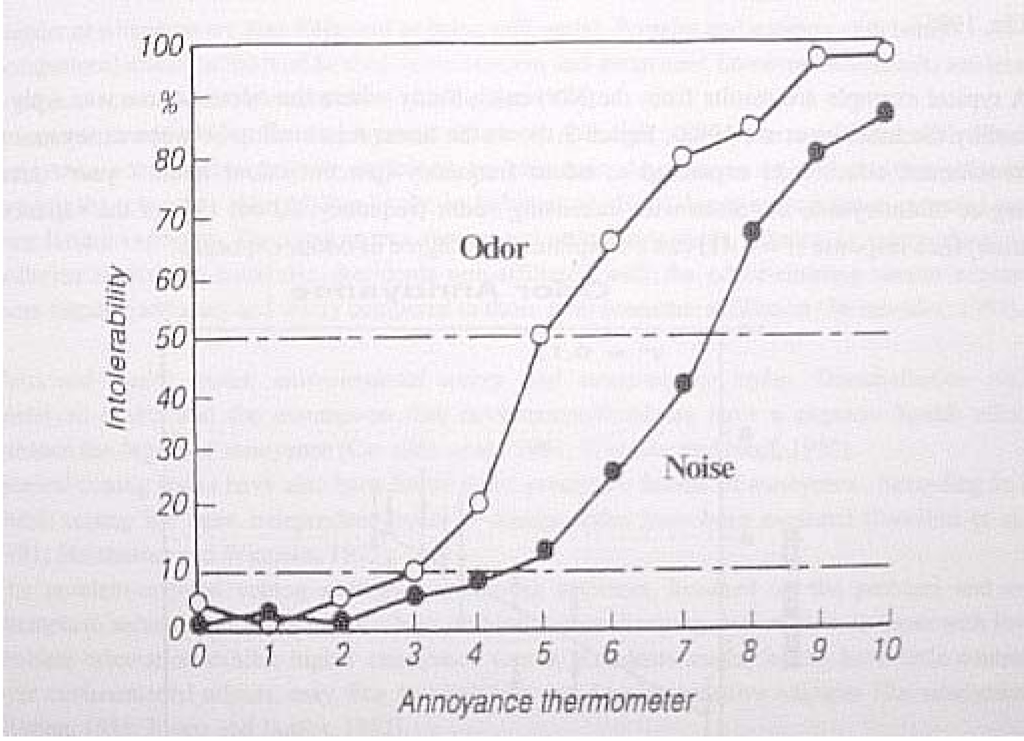


Figure 20 Relationship between 'intolerability' by questionnaire and annoyance thermometer rating, for ambient stressors noise and odour. Source: VDI3883, Part 1, page 26

A clearly statistically significant relationship between the percentage of ‘Odour Hours’, as determined by the German ‘Field Panel Method’ and the response of surveyed members of the public in the annoyance thermometer has been found, with a regression coefficient of $r \sim 0.70$ (Steinheider e.a., 1998).

In the Netherlands dose-effect studies have been carried out since the late 1980's (Cavalini, 1992). Survey techniques were used to establish odour annoyance as a health effect, such as the STQ (or TLO) survey methodology as described in section 0. In some cases slight variations were made to the methodology employed, mainly consisting of differences in the method of approaching the subjects: by phone, by mail or in face-to-face interviews (Miedema et al, 2000). In some cases, the annoyance is classified on a scale, to differentiate between *annoyed* and *seriously annoyed.*

Dose is typically determined as calculated odour exposure on the basis of measurements or estimates of source odour emission rates using atmospheric dispersion modelling. This leads to exposure expressed as a concentration that is exceeded with a particular probability for a particular averaging time, producing parameters to characterise dose such as $C_{98,\ 1\text{-hour}}$ as described in section 0. A relatively simple Dutch regulatory model, LTFD, was used to calculate exposure.

In a recent paper (Miedema, 2000), the results of fourteen surveys carried out around eleven different types of industrial sources in the Netherlands in the late 1980's and early 1990's have been reviewed. These studies involved a total of 6276 survey results. The types of odour are reflected in Table . All data had been reported previously.

In this paper, the raw data of the previously reported studies were re-analysed to establish a relationship between dose (odour exposure) and effect (percentage of population annoyed). The statistical model applied in these studies shows a strong correlation for all but one of the studied cases. For the combined data for all studies, the correlation coefficient *r* is 0.889. The review paper demonstrates that the correlation coefficient improves to *r* is 0.945 when an additional variable is introduced to represent odour annoyance potential.

Method A	Method B
Unpleasant	
Oil extraction	Rendering
Chemical plant	Oil extraction
Rendering	Chemical Plant
Pig Farm	Pig Farm
Sugar factory	Grass drying
Grass drying	Sugar factory
Frozen Chip production	Frozen Chip production
Wire coating	Pastry factory
Pastry factory	Wire coating
Cacao processing	Cacao processing
Tobacco processing	Tobacco processing
Pleasant	

Table 6 Ranking of (bio-)industrial odours according to their perceived 'pleasantness' as determined in two types of laboratory experiments.

The odour annoyance potentials used in this study have been established in laboratory tests using assessors. The odours were presented at a defined odour concentration, e.g. 25 $ou_E \cdot m^{-3}$. Two methods were used, both leading to a ranking of odours according to their *annoyance potential*. Method a.) used paired comparison, while method b.) used a nine-point reference scale, with H_2S providing a reference for scale value 2 on the unpleasant end and amyl acetate referencing value 8 on the pleasant end of the scale. The ranking of the odours according to their 'pleasantness' is presented in Table on this page. This table compares to the ranking obtained by a different methodology, presented in Table , section 0.

When interpreting the results of the review paper (Miedema et al, 2000) two issues must be kept in mind:

- The odour units used in the review paper are odour units as used in the Dutch NVN2820 standard. The relationship with European odour units as defined in EN13725, as used throughout this report is: 1 $ou_E \cdot m^{-3}$ = 2 ou/m^3.
- The annoyance is expressed as percentage of questionnaire respondents *seriously annoyed* (%HA). This approximately represents the top third of people '*annoyed*', which is the measure used in all other studies reviewed in this section.

The relationship between the percentage of respondents scoring *seriously annoyed* and the calculated odour exposure, for all study cases combined, was:

$$\%HA = 4.775 \cdot \log(C_{98})^2$$

This implies that at an exposure level of $C_{98,\ 1\text{-hour}} = 5.3\ ou_E \cdot m^{-3}$ the percentage of respondents *seriously annoyed* by odours is 10%. With the uncertainty of the STQ survey method estimated to be ± 3% this finding implies that the annoyance level is a clear and statistically significant indicator that the odour exposure leads to a behavioural change in the exposed population that can be clearly measured using the survey technique.

The dose-effect relationship is further substantiated by the results of an extensive dose-effect study held in 1999-2000 that was funded by the Ministry of Public Housing, Planning and the Environment in the Netherlands. The study was carried out with a view to providing a more scientific basis for odour nuisance management through licensing of intensive livestock units. This was deemed necessary by the State Council, the highest appeal court in planning matters, to remove doubts about the justification of relaxing the regulations for setback distances around pig production units (Bongers e.a., 2001B). The dose-effect relationship for odour annoyance caused by pig production unit odours was established in a study involving approx. 2300 residents exposed in different degrees to odours from pig production units, that was carried out in 1999 (Bongers e.a., 2001A). The results of this study were first presented in the verbal conference presentation of paper Bongers, 2001B.

The study was sufficiently large to enable analysis of the differences in nuisance sensitivity in subgroups, such as rural and town population, those professionally involved with agriculture, residents of 'pig farming concentration areas' etc.

The dose-effect relationship for pig odours is therefore currently relatively well documented and can be used as a tool for predicting odour annoyance levels in a population.

The dose-effect relationship was determined by studying the following variables:

- Odour exposure, calculated using dispersion modelling (LTFD[1] model), as the hourly concentration at the 98-percentile of 1-hour averaged concentrations in a typical meteorological year (see section 0)
- Percentage of a sample of the population classified as 'occasionally or frequently annoyed' on the basis of their responses in a standardised questionnaire, using interviews by telephone (see section 0 for details).

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[1] Lange Termijn Frequentie Distributie Model. Translated: Long-term frequency distribution model. This model was a National regulatory model until 2000, when it was replaced by a new modern Gaussian model.

The relationship between odour exposure and percentage of the population 'annoyed' was analysed using the statistical model as described in section 0. The correlation turned out to be highly significant with correlation coefficients $r > 0.9$. The dose-effect curves for percentage annoyed, as predicted from calculated exposure (C_{98}) in situations where a single pig production unit causes the exposure (other sources have no relevant influence on the exposure), are shown in figure 21

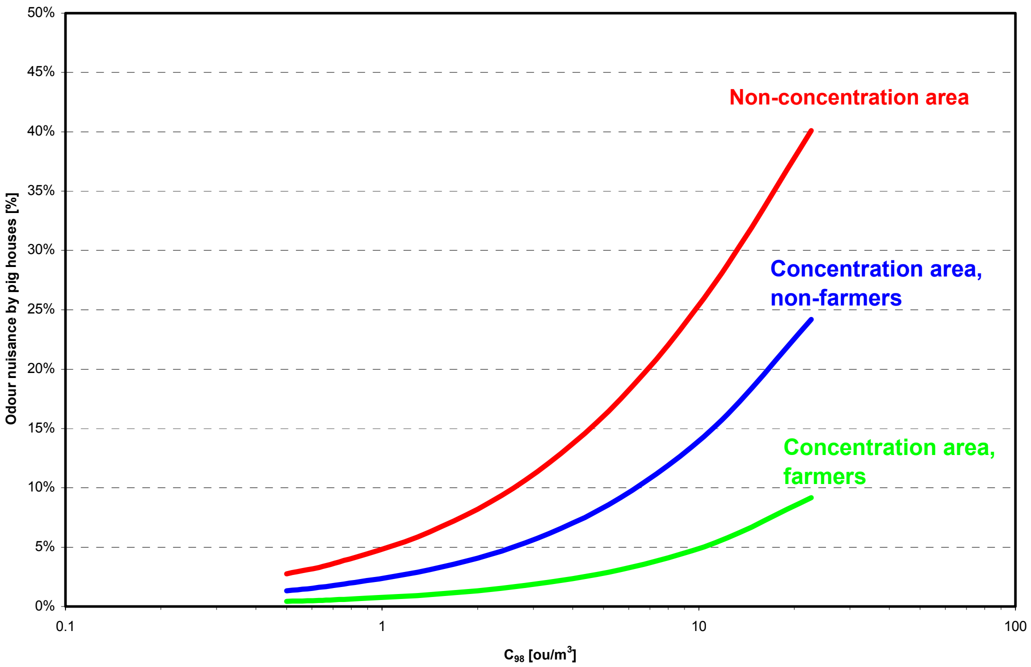


Figure 21 Relationship between percentage of population experiencing 'annoyance' (effect) and calculated odour exposure (dose) for one-source situations, expressed as C_{98}, the 1-hour averaged odour concentration at the 98-percentile for a normal meteorological year . Note: 2 Dutch ou/m^3 = 1 ou$_E$·m^{-3} (Source: Bongers, 2001A, also presented verbally at conference with paper Bongers 2001B)

The figure shows that:

- 10% of the respondents from the general public score as 'annoyed', when exposed to pig odours from a single piggery in the vicinity, at an exposure level of $C_{98,\ 1\text{-hour}} = 1.3$ ou$_E$·m^{-3} .
- In a selection from general public of those resident in a pig concentration area, where pig odours are a common feature of the odour context of the area, 10% of the respondents that are exposed to odours emanating from a single piggery are annoyed at an exposure level of $C_{98,\ 1\text{-hour}} = 3.2$ ou$_E$·m^{-3} .
- Those who are directly involved in agriculture were found to be the most 'pig odour tolerant' selection of the population. For this group, with the lowest nuisance sensitivity, the 10% annoyance level is reached at an exposure of $C_{98,\ 1\text{-hour}} = 13$ ou$_E$·m^{-3}.

These data are highly relevant for determining an exposure limit for odour impact, on the basis of statistically highly significant behavioural effects indicating odour-induced annoyance. The dose-effect relationships indicate that for an odour with a relatively high annoyance potential, can be detected in a 'normal' population at an exposure of $C_{98,\ 1\text{-hour}} \approx 1.3$ ou$_E$·m^{-3}. For a population where the odour is a more common feature of the environment, due to a high concentration of similar odour sources, the effect is detected at higher exposure of $C_{98,\ 1\text{-hour}} \approx 3.2\ ou_E{\cdot}m^{-3}$. It is not known whether this apparent higher tolerance is caused by lower nuisance sensitivity due to adaptation and modified coping behaviour or alternatively by self-selection caused by gradual departure of those within the original population with a lower tolerance to odours. At an exposure level of $C_{98,\ 1\text{-hour}} \approx 13\ ou_E{\cdot}m^{-3}$ even those with a direct financial stake in agriculture showed a clearly significant behavioural annoyance response with 10% of that selection of the population scoring as ‘annoyed’. This value can be regarded as indication for a maximum level of exposure that can be associated with “acceptable odour annoyance” for an odour with relatively high annoyance potential such as pig odour.

From these data it would appear that the exposure level of $C_{98,\ 1\text{-hour}} < 5\ ou_E{\cdot}m^{-3}$ that has been applied and accepted as a criterion for avoiding nuisance in the legal sense in a number of cases in the UK as first accepted in the planning procedure at Newbiggin-by-the-Sea (Department of the Environment, 1993) is evidently not erring on the side of caution, assuming that pig odours and wastewater treatment odours have similar odour annoyance potential.

Further statistical analysis of the data yielded some relevant conclusions (Bongers, 2001B):

1. The ‘nuisance sensitivity’ of people exposed to one single source was higher than for those exposed to two or more sources, when all sources were included in the exposure model.
2. The best fit for annoyance percentage as a function of odour exposure was obtained by considering the one dominant source only. When exposure was calculated in this manner, the difference between respondents in one-source and multiple source situations was no longer apparent.
3. The nuisance sensitivity of people who are *directly professionally involved* in agricultural livestock production was found to be significantly lower than that of the general population living in a similar area. This effect is even more pronounced for those living in ‘pig production concentration areas’ where the agricultural population displays a markedly more tolerant attitude, leading to lower levels of annoyance at a given exposure to odours than in all other groups.
4. Whether people lived in a rural or more (sub-) urban environment did not have a significant effect on their nuisance sensitivity. Only people living in ‘pig production concentration areas’ showed lower nuisance sensitivity than in other areas, indicating a higher tolerance to pig odour exposure, when cumulated exposure was calculated incorporating all relevant sources.

6.1.1 Complaint reviews

Comprehensive reviews of incidence of complaints in relation to odour exposure for the UK are not available.

From the consulting experience of the authors there are indicative data for solid domestic waste processing facilities that would indicate that between 65 and 90% of complaints occur within areas exposed to odours at a level of $C_{98,\ 1\text{-hour}} \leq 5\ ou_E{\cdot}m^{-3}$.

A review of complaints around wastewater treatment facilities, reported at a workshop of UK Water Industry Research in 1999, indicated that over 95% of complaints registered around half a dozen wastewater treatment works occurred at exposures in excess of $C_{98,\ 1\text{-hour}} = 5$

$ou_E \cdot m^{-3}$ while approx. one third of complaints were registered at exposure levels in the exposure range $5\ ou_E \cdot m^{-3} \leq C_{98,\ 1\text{-hour}} \leq 10\ ou_E \cdot m^{-3}$.

It should be emphasized that while complaints are a clear indicator of annoyance, the absence of complaints does not imply the absence of annoyance.

6.1.2 Relevance of the results of dose-effect studies in setting air quality criteria for odours

The results obtained in dose-effect relationships, presented above can be used as the starting point for a set of limit and target values for exposure, associated with differentiated levels of protection against nuisance.

The main starting points in the argument supporting such criteria are:

1. The aim of an environmental quality criterion for odour is to avoid a measurable and clearly statistically significant behavioural annoyance response in terms of annoyance caused by exposure to odours.
2. The correlation between surveyed annoyance and calculated exposure is statistically highly significant, with correlation coefficients $r > 0.9$.
3. The uncertainty of the survey method is in the order of ±3% (percentage points annoyance in the surveyed population).
4. Consequently, an annoyance level of 10% is clearly greater than the ‘unexposed’ background of approx 3% annoyed, and can therefore be considered as a value where the annoyance level caused by odour exposure is highly unlikely to be caused by measurement uncertainty.

The level of 10 % of respondents annoyed is proposed as a practical guide value, which is well above the ‘background’ or ‘baseline’ level for odour annoyance, as assessed in areas not exposed to (bio) industrial odours. The value of 10% annoyance as an operational criterion should be regarded as a value where an effect is detectable with a high degree of confidence.

When the Environment Agency would consider defining a guideline level of ‘acceptable annoyance’ the 10% value can be used as a starting point. However, the judgement on a suitable environmental quality objective for odours is ultimately a matter of policy rather than an issue of scientific investigation. This value can be lowered, creating a safety margin, or increased, indicating an acceptance that a certain level of annoyance and a real risk of nuisance is deemed acceptable.

What is acceptable or unacceptable as a level of annoyance is a matter of policy and consensus on priorities and aspirations of a society. Scientific investigation can do no more than indicate a level where an effect is clearly detectable in the population.

Once a criterion is identified, a regular review of the practical experience of application is required to ensure that the criterion is effectively reflecting the environmental quality requirements of society. The value may need adaptation to a gradual shift in the expectations of the population, with time, where the quality of their living environment is concerned. Scientific surveys can identify the exposure level where a significant annoyance effect occurs. How much more exposure is acceptable is an issue where policy makers need to be the arbiter rather than consultants and scientists.

The stated policy objective of the regulator in the Netherlands, for example, is to limit the fraction of people annoyed by odours to 12% (VROM, 1988), initially expressed as 'no more than 750,000 residential dwellings exposed to annoying odours'. This regulatory objective was a policy decision rather than a target with a well-reasoned scientific motivation. The policy objective was originally made operational by implementing exposure limits of $C_{98,\ 1\text{-hour}} < 0.5\ ou_E \cdot m^{-3}$ for existing sources and a firmer $C_{99.5} < 0.5 ou_E \cdot m^{-3}$ for new licence applications on greenfield sites (VROM, 1984). These criteria, which were applied until 1995, have been demonstrated to be effective to reduce annoyance in the residential environment. After these air quality criteria were applied in the regulatory practice in the Netherlands between 1985 and 1995 in hundreds of licensing cases, their effectiveness was verified by interviewing the local authorities involved in licensing and enforcement of these cases and by reviewing residual complaints data. The conclusion was that the implementation of the policy produced overall satisfactory results, for the Dutch regulatory environment (Dönszelmann, 1991). This is an important observation. The exposure criteria that were applied, supported by the practical experience of their application, were effective in reducing odour annoyance to levels that are deemed 'acceptable' by the local authorities involved in a large number of actual cases. However, from an economic standpoint, it may be that these limits were too severe (see section on regulations in the Netherlands in Annex A).

From the dose-effect study for pig odours described above, indicative levels of exposure can be derived for pig odours, where the annoyance levels of the population are increased above background, and the increase is clearly correlated to odour exposure.

There is clear and compelling evidence that at an exposure level of $C_{98,\ 1\text{-hour}} > 13\ ou_E \cdot m^{-3}$ even the most tolerant selection of the public, with a direct financial stake in the industry producing the odours, show a measurable behavioural result in terms of percentage annoyance (anon., 2001). It should be clearly emphasized that this value is indicative for a group with minimum nuisance sensitivity and hence the greatest tolerance. This value would not be suitable as a criterion for protecting the amenity of the general public.

The most tolerant sample of the general public, for whom pig odours are a regular feature of their living environment in a 'pig production concentration area' with multiple sources, showed 10% annoyance associated with an exposure level of $C_{98,\ 1\text{-hour}} \approx 3.2\ ou_E \cdot m^{-3}$ (anon , 2001). This finding, combined with the reported overall result for a selection of a dozen (bio)-industry odours that 10% of respondents experience *serious annoyance* at exposure levels of $C_{98,\ 1\text{-hour}} \approx\ 5\ ou_E \cdot m^{-3}$ (Miedema, 2000), supports criterion for 'acceptable' odour exposure to odours with relatively high annoyance potential that should be no higher than $C_{98,\ 1\text{-hour}} \leq 3\ ou_E \cdot m^{-3}$.

For the general population as a whole, firm data indicate that exposure at $C_{98,\ 1\text{-hour}} \approx 1.3\ ou_E \cdot m^{-3}$ is associated with 10% annoyance, based on a substantial set of data with *n* = approx. 1500 respondents (anon., 2001). This would suggest a target value for odour exposure at a value of $C_{98,\ 1\text{-hour}} \leq 1.5\ ou_E \cdot m^{-3}$, that would be appropriate to limit annoyance to a level where a behavioural effect can just be detected with high statistical confidence.

It should be noted that these criteria are based on dose-effect studies carried out in the Netherlands. These dose-effect relationships cannot be transposed to another situation or country without considering possible local aspects that could influence the nature of the relationship. Environmental criteria should be set specifically for the entity (nation or region) in question, reflecting a level of environmental quality and protection compatible with the aspirations of its society. Ideally, dose-effect relationships for UK citizens in UK conditions should be assessed experimentally, to confirm the findings obtained abroad.

The data presented above are valid for odours on the unpleasant end of the odour annoyance scale. In principle, using methods for assessing annoyance potential currently being developed, it is feasible to arrive at a form of differentiated criteria for odour exposure, depending on odour annoyance potential. This would lead to more lenient criteria for less unpleasant odours. Based on indicative data and practical experience in the Netherlands the correction factor for practical environmental odours will be less than a factor 10 in $C_{98,\ 1\text{-hour}}$ values for odours on the extremes of the annoyance potential scale, such as rendering on the high annoyance potential extreme and coffee roasting or bakeries on the low end of the scale. (see Section 7.2, Table).

The next chapter presents a conceptual framework that uses general dose-effect relationship criteria to set an initial air quality criterion for odour based on odour exposure expressed as the familiar $C_{98,\ 1\text{-hour}} < x$ $ou_E{\cdot}m^{-3}$ limit, with a mechanism to apply corrections for annoyance potential to tailor these values to a specific odour and its annoyance potential and a specific exposure situation around a source.

7. PROPOSED CONCEPTUAL MODEL FOR ODOUR IMPACT ASSESSMENT

Different countries apply a variety of approaches for regulating odour impact. An overview of relevant regulations and proposed regulatory frameworks is provided in Annex A.

To provide a starting point for a suitable guideline on odours for the United Kingdom, a conceptual framework to assess odour impact with a view to setting licence conditions for specific installations is outlined in this chapter. This framework will rely on the epidemiological dose-effect studies presented in chapter 0.

Before outlining the conceptual framework two important questions are discussed in separate sections:

- How to set a level of 'acceptable annoyance' to determine an acceptable exposure level?
- Is the difference in odour annoyance potential of odours relevant to their impact?

To answer the first question potential approaches are discussed, and the selection of the most suitable conceptual approach is motivated.

The second question is relevant to the decision whether one criterion for odour exposure would suffice. If that is not the case, any conceptual model for regulating odour impact should provide a mechanism for differentiating odour impact criteria depending on the character of the specific odour released into the atmosphere. The relevance of differences in odour potential is therefore reviewed with a view to determining how far these differences can be used to make the impact assessment of impact more specific.

Finally, a conceptual model is outlined that could be used for impact assessment of odours in specific situations, using a transparent set of criteria to reach an end conclusion on the acceptability of the impact. Such a framework, once made operational, can assist in improving the quality of the regulatory decision making process by providing both a listing of the factors to be considered and a mechanism for considering these factors in a decision making process. The framework aims to leave sufficient scope for considering local circumstances while providing a firm basis for the impact assessment, starting from generic limit or target values derived from general dose-effect relationships. The model is designed to have sufficient flexibility to incorporate new developments in odour impact assessment and practical experience with application of criteria while maintaining transparency and continuity in its administrative application in licensing.

7.1 How to set a level of 'acceptable annoyance' to determine an acceptable exposure level?

There are two fundamentally different approaches to determining a level of 'acceptable annoyance' with a view to defining a quantitative air quality criterion based on a level for 'acceptable exposure':

- Deterministic approach;
- Empirical approach.

The characteristics of these two approaches are discussed in the following sections.

7.1.1 Deterministic approach

The deterministic approach assumes that the entire process leading from formation to annoyance, as described in section 4.3, can be described and quantified in terms of all its variables and their interactions.

However, in practice attempts to construct a deterministic model typically involves a drastically simplified process that assumes that perception, on a second to second basis, would lead to annoyance in a straightforward 'push button' manner. Typically, the emphasis is on modelling exposure, while the receptor variables (context, socio-economic factors, appreciation, attitude to source, and associations) remain underexposed.

Detailed modelling of short term fluctuations of exposure is assumed to have a predictive value for the process leading from:

production of odorants → transfer to atmosphere → atmospheric dispersion → exposure → population → perception → appraisal →annoyance →complaints

The mechanisms that lead from exposure to annoyance are then grossly simplified, ignoring the known interactions of factors such as behavioural status, coping strategy, previous experience in memory and context in the process of cognitive appraisal. This simplification leads to application of a simple linear model linking modelled short-term exposure to the immediate response of annoyance, based on generalised assumptions from laboratory experiments on perceived intensity:

- 1 $ou_E \cdot m^{-3}$ is detection,
- 5 $ou_E \cdot m^{-3}$ faint odour and
- 10 $ou_E \cdot m^{-3}$ distinct odour.

Annoyance is assumed to occur between 5 and 10 $ou_E \cdot m^{-3}$

7.1.2 Empirical approach

In this approach, the actual causality between the parameters that describe the process that leads from exposure to nuisance, as described in section 4.3, is not an issue. It recognises that both exposure related factors and receptor (people) related issues play a role. This approach assumes the inherent inability to construct a complete model of causality, explaining all variables, and their interactions, that contribute to nuisance potential. Emission measurements at source are used in combination with dispersion modelling as a 'best available option' to describe exposure (dose), providing a better yardstick than, for example, distance. Actual assessment of annoyance levels in the population by survey are considered as the best available option to quantify the dependent variable (effect). The correlation between the independent variable (modelled exposure) and the dependent variable (surveyed annoyance) is then established through epidemiological field studies. In this approach, the best possible yardstick is accepted, with its shortcomings, and a mark is placed on this yardstick where the effect 'annoyance' can be reliably detected. This exposure level can then be used as a starting point for determining an administrative 'acceptable annoyance' level.

7.1.3 What is the most suitable approach: deterministic or empirical

To answer this question we need to look at the reality of our ability to describe factors that contribute to the epidemiological effect 'annoyance'. A simple push button model would be very convenient. However, the workings of the human sense of smell are more complicated. It is not a simple linear or proportional physiological reaction to a stimulus. The sense of smell does not merely detect. It perceives and then interprets the perceived odour and its relevance in terms of context, current individual state (e.g. hunger, relaxation) and past experience (associations). This implies that the signal is processed not only at a basic level, in the hippocampus (limbic system) but also in the cortex. Almost anyone will know from personal experience that smell can be extraordinarily powerful in evoking memories and experience, usually of an almost cinematographic clarity, and with strong emotional connotations. These memories, stored in the cortex, can be evoked by smells, even after many years. It is no coincidence that a common treatment for amnesia is exposing patients to olfactory stimuli to try and access their latent memory.

Recent studies of the areas of the brain that are involved in the process of olfactory perception point towards close interaction between the hippocampus, controlling basic flight-fight reactions and long term memory, and the cortex.

An understanding of sensory perception and its evolutionary relevance is crucial to understanding the mechanism of:

exposure → detection → perception → appraisal→ annoyance → nuisance.

In this concept, described in more detail in section 4.3, the *perception* of smell is always followed by cognitive appraisal. The individual interprets the relevance of a smell through connotation, assigning meaning to that particular smell in the context of the moment. This is a complex process that is not only driven by physiology, but also by a cognitive process that involves the accumulated experience of the individual. When this model of the sensory perception of smells is accepted, the crude mechanistic deterministic model loses plausibility.

The reality of being able to describe these higher cognitive interactions sufficiently to allow extrapolation of simple sensory appraisal tests in the laboratory to actual prevalence of annoyance in a deterministic model seems remote.

The exposure to the stimulus on a second to second time scale may be modelled, making the assumption that the relationship between year, day and hour distributions can be extrapolated to the minute and hour level. However, this would not in any way address the variation in the factors that determine the perception and cognitive appraisal in the receptors (people). The perception of the smell and the appreciation may vary from person to person, depending on their stored memories and associations. Within one person, the perception may also change with time, depending on the context of perception and the state of the individual (hungry, resting, socialising etc). These processes that in the end determine appreciation of a certain odour stimulus are as yet poorly understood and certainly not fitted into a mathematical model.

Acknowledging the lack of understanding of the model of perception, it is almost unavoidable to take the pragmatic approach, in which the effect of ‘annoyance’ is linked to modelled ‘exposure’, considering the intermediate mechanisms, to some degree, as a black box. This approach is not uncommon in epidemiology.

7.2 Is the difference in odour annoyance potential of different odours relevant to their impact?

Evidently, not all odours are the same in their ability to cause annoyance. A bakery or a coffee roaster produce odours that are more tolerable than those produced in animal rendering. To account for these differences in quantitative terms for all environmental odours between those extremes is not that simple, however. This is the reason why until now most calculations used to predict the impact of odours involve the simplification of characterising odours in terms of detectability only (using the odour concentration) which does not take into account the difference in annoyance potential between odours. Using odour concentration reduces the question of 'how strong is this odour?' to a detection threshold. The 'odour level' or intensity is characterised in odour units or odour decibels, which are both multiples of the concentration at the detection threshold. This approach is very similar to the approach in noise regulations (see also section 0).

This simplification is useful, as it allows calculations in concentration terms, compatible with the general concepts of air quality criteria. It is, however, important to be aware of the limitations of this simplification, and to consider the characteristics of the odour at hand, relative to other odours.

The task of assessing odour annoyance potential can be divided in two steps:

- *What is the odour annoyance of an unknown odour relative to another odour?* When this question can be answered we can construct a ranking of odours, from the maximum odour annoyance (e.g. some odours from animal rendering) to minimum odour annoyance potential (e.g. bakeries)
- *What is the magnitude of the difference in odour annoyance potential of two odours?* This question would help in not only determining a rank order for odour annoyance potential, but also determine the relative distances between the odours on a scale of annoyance potential.

Can we distinguish differences in attributes of odour at intensities above the detection threshold? Obviously, we can characterise odours in semantic terms. A method using 140 standard descriptors has been developed to do so (Amoore, 1983). The relative unpleasantness (hedonic tone) can even be predicted from these descriptors (Amoore, 1985), to some degree.

Also, the characteristics of the relationship between odour concentration in odour units or dB_{od} and perceived intensity can be used to distinguish different odours. Common sense would suggest that odours with a steeper rise of intensity with concentration may have a greater impact than those with a more gentle rise, bearing in mind the fluctuating exposure after dilution in the atmosphere. These differences can be established experimentally, even for apparently similar odours, as was demonstrated experimentally for pig slurry and poultry manure odours (Misselbrook e.a., 1993), see Figure 22. Comparison of the graphs shows that the increase in perceived intensity is less steep for pig slurry odours than for broiler odours, which are particularly pungent because of their high ammonia content.

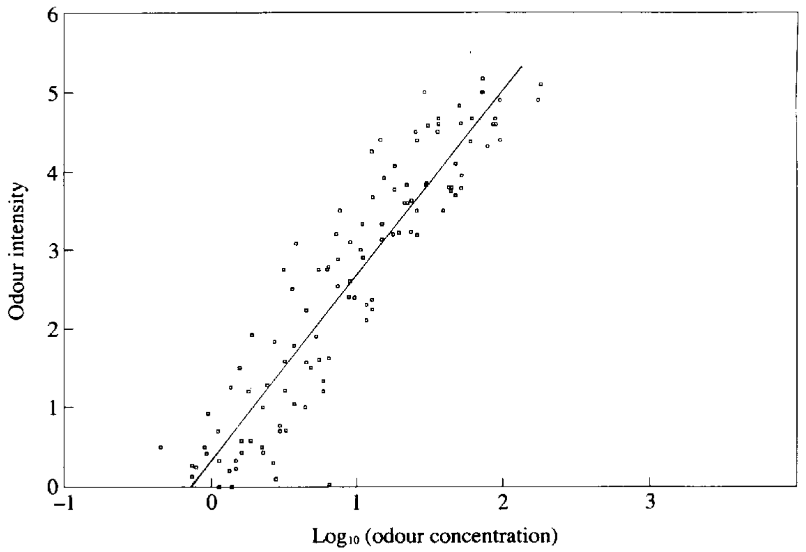


Fig. 2. Relationship between intensity and concentration for odour emissions from broiler houses

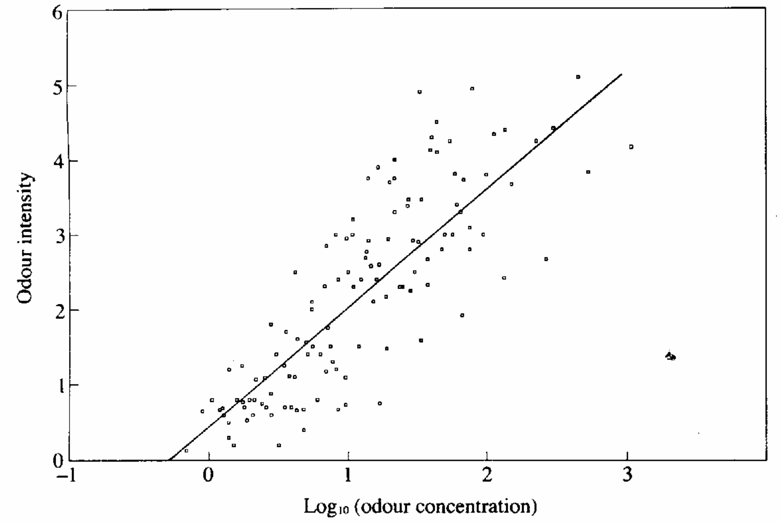
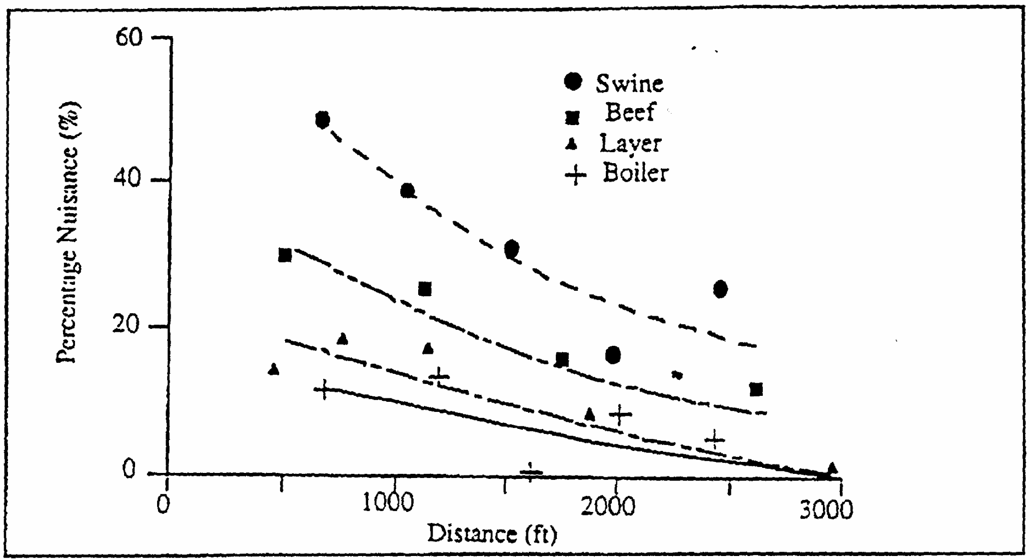


Fig. 1. Relationship between intensity and concentration for odours following application of pig slurry

Figure 22 Relationship between odour concentration and perceived intensity, for broiler house odour and the odour of pig slurry after application. From Misselbrook TH, Clarkson CR, Pain BF: Relationship Between Concentration and Intensity of Odors for Pig Slurry and Broiler Houses. Journal of Agricultural Engineering Research 55: 163-169, 1993.

However, the assumption that a steeper rise characteristic for intensity would indicate greater impact is disputed by reported results of actual impact studies as shown in Figure 23 where pig odours are clearly shown as having a greater impact in terms of nuisance, while having the less steep intensity curve (Veenhuizen, 1996).



Nuisance perception and separation distance.

Figure 23 Relative nuisance perception for different livestock odours, source: Veenhuizen, 1996.

A very straightforward approach to compare odour annoyance potential of different odours is to ask a group of people to rank a list of twenty descriptors of odours, according to like and dislike. In doing so, you can tap the 'sensory memory' of your subjects, where the reference to previous exposure, including the influences of context, associations etc. This approach has been used in research for generic, everyday odours (Dravnieks, 1984). More recently, this approach has been applied to rank environmentally relevant odours, using groups of people who deal with odour annoyance professionally. The ranking order of a list of twenty industrial and agricultural odours was found to be remarkably consistent, when applied to two groups of people attending an odour annoyance seminar (one group in the Netherlands and another group in Germany). The results for the Dutch group are presented in Table . The ranking is strictly on rank order, it does not provide a comparative magnitude.

It is interesting to compare the ranking technique with odour exposure criteria that have been set for specific industries in the Netherlands, see Table , Annex A1. These exposure criteria are only partly based on epidemiological data, as they are the result of a consensus building process between the regulatory agency and the industry involved (Infomil, 1996, Infomil, 2000). These values can be seen, however, as an expression of the consensus reached in that society on the relative odour annoyance potential of these odours. The ranking as seen in Table is, to a reasonable degree, reflected in those agreed air quality criteria in Table , Annex A1.

Descriptor	Ranking	Ranking	Descriptor
Generic odours	mean	mean	Environmental odours
Roses	3.4	1.7	Bread Factory
Coffee	4.6	4.6	Coffee Roaster
Orange	5.8	5.1	Chocolate Factory
Cinnamon	6.0	8.1	Beer Brewery
Mowed lawn	6.4	8.3	Car Park Bldg
Soap	7.3	9.4	Charcoal Production
Hay	7.5	9.6	Frozen Chips production
Brandy	7.8	9.8	Eel smoking
Raisins	7.9	9.8	Car Paint Shop
Beer	9.3	9.8	Sugar Factory
Cork	10.5	9.8	Fragrance & Flavour Factory
Peanut Butter	11.1	11.2	Asphalt
Cleaning Agent	12.1	12.8	Livestock odours
Sauerkraut	12.8	12.9	Wastewater Treatment
Wet Wool	14.1	13.2	Livestock Feed Factory
Paint	14.4	13.2	Refinery
Vinegar	14.8	14.0	Green Fraction compositor
Sweat	17.2	14.1	Landfill
Sour Milk	17.5	15.7	Fat & Grease Processing
Cat's Piss	19.4	17.0	Slaughter House

Table 7 Ranking of twenty generic and twenty environmental odours according to like or dislike by a group of people professionally involved in odour management, in the Netherlands, 1997.

The information presented in this section indicates that it is useful to take a measure of annoyance potential of the odour in question into account when considering the impact of odours on residential population. Although the methodology to express odour annoyance potential in quantitative terms is still being developed, it can be demonstrated from available data that for most odours the differences based in perceived impact will be limited to 7 dB_{od} (a factor 5) in terms of exposure, expressed as C_{98}.

Given the magnitude of these annoyance potential differences on the impact as expressed in odour concentration units or dB_{od}, a unified air quality criterion for all odours alike cannot be justified. A conceptual framework for assessing and potentially regulating odour impact must include some mechanism to account for differences in odour annoyance potential.

7.3 Conceptual model for odour impact assessment in the United Kingdom

On the basis of currently available methodology and data it is not possible to propose a fully validated deterministic quantitative methodology for assessing odour impact and nuisance potential in the United Kingdom. There are many tools available, however, that can be integrated in a pragmatic conceptual model for administrative use supporting licensing decisions. This model combines quantitative data with qualitative judgements of local conditions to arrive at a judgement on an acceptable level of exposure to avoid nuisance. This approach can assist in achieving a more transparent and consistent decision making process for managing odour impact in planning and licensing.

7.3.1 Requirements for a model that is applicable in regulatory practice

Methods for direct assessment of nuisance in a population are appropriate only in existing situations. A pragmatic conceptual model should therefore go further and predict nuisance potential for new plants as well as existing ones.

A method to assess odour impact and to determine a level of exposure associated with 'acceptable' annoyance levels should have both descriptive and predictive capabilities, to be useful in the licensing and planning process.

An effective regulatory model also allows enforcement through measurement. Verification of the air quality criterion for odour exposure must be feasible, preferably through reduction to emission limits that can be assessed through stack emission measurements at source.

7.3.2 Availability of suitable methodology

A method for characterising and predicting nuisance potential should provide a model that describes the process that leads from emission to nuisance, as described in section 4.3.

Nuisance potential = ψ*(emission characteristics, exposure, nuisance sensitivity, context)*

Until recently, exposure was invariably characterised on the basis of detectability only, using the odour emissions in $ou_E \cdot s^{-1}$. To take into account the differences in their potential to cause annoyance for various environmental odours, ranging from bakeries to rendering odours, this characterisation can be improved by adding assessment of annoyance potential. If a method for characterising odour annoyance potential is available, the expression ψ*(emission characteristics)* can be detailed and developed into:

ψ*(emission characteristics)* = ψ*(annoyance potential, odour concentration, volumetric flow)*

The feasibility of developing a standardised, validated method for measuring annoyance potential has been reviewed. The conclusion was that such a method can be developed (van Harreveld, 2000). Until such a laboratory method is available (expected 2002) existing rank order data for industrial data as shown in Table can be used to make a simple three category distinction of odours:

- Low odour annoyance potential (e.g. bakeries, coffee roasters)
- High odour annoyance potential (e.g. animal rendering, fat & grease processing etc.)
- Medium odour annoyance potential (all odours not in categories High or Low).

The methods to determine the other elements required to characterise odour emissions, *odour concentration* and *volume flow* are well established and standardised.

The characterisation of exposure relies mainly on dispersion modelling. Improvements in models used and their usage are feasible to achieve a better description of exposure, such as the introduction of peak-to-mean ratio estimates (see section 0) are possible, but require validation. A model is only 'better' for predicting annoyance level if it has been demonstrated to provide a better 'fit' of the regression line in actual dose-effect data. Breakthroughs in exposure modelling methodology are currently not obviously imminent.

To describe the characteristics of the exposed population in terms of nuisance sensitivity, a number of factors that can be relevant have been identified (see section 0). Their interaction and quantitative interactions are not known, however. There are indications that the issue is not straightforward, and even highly complex. It is therefore not possible to incorporate these factors as quantitative terms in a conceptual model. They can, however, be incorporated as qualitative risk factors, combined with a degree of common sense to interpret their relevance in a particular situation.

Factors that can be considered relevant for nuisance sensitivity are:

- Prevalence of health complaints
- Perceived health risks associated with the source of the odour
- Coping strategy
- Economic conditions and economic relations with the odorous activity
- Age
- Satisfaction with the residential environment.

Similarly, factors can be identified to describe the ample notion of *context* that have been demonstrated to be relevant to the level of annoyance. However, as for nuisance sensitivity, the magnitude and interaction is not known in quantitative terms. Again, these factors can be incorporated in a conceptual model as qualitative risk factors only. Examples of factors that have been identified are:

- Rural odours in an urban context
- Industrial odours in a rural context
- Cumulative effects of multiple sources of odour impacting on the same area.

Miscellaneous factors can be incorporated in the model as qualitative risk factors:

- 'Peak fluctuations" of exposure, based on estimated peak to mean factors (depending on factors such as near/far field, source shape).

In the next section a conceptual model is proposed that is built from the factors described.

7.3.3 The proposed conceptual model for odour impact assessment

The proposed conceptual model for assessing and predicting odour impact in terms of nuisance potential is aimed at providing a transparent structure for decision making in the framework of licensing and planning procedures. It does not claim to be a full, deterministic description of all processes and factors that have an influence, and their interactions. It does provide a pragmatic model that can serve to compare the underlying assessment in different situations. It can also be used to review assessments in time, when priorities and options may develop.

The conceptual model consists of two main parts:

- A 'hard' quantitative assessment through measurement of annoyance potential, odour concentration and volume flow, to characterise the emissions of odour in terms of annoyance potential. This parameter can be used in combination with dispersion modelling to describe and characterise exposure, and predict annoyance using epidemiological dose-effect data. This method would be an improvement over the current method using odour concentration and volume flow only. Instead of producing a measure for exposure to odour, a differentiation would be made to approximate the emission to malodour, as characterised by the annoyance potential.

- A 'soft' quantitative correction by using qualitative factors affecting the nuisance potential in combination with weighting factors, that can be adapted to the locality in question. In this manner, factors such as nuisance sensitivity of the exposed population duration of activity and the context in which the exposure occurs can be taken into account. The magnitude of the influence of these factors and the quantitative nature of their interrelationships is not substantiated in quantitative terms.

> That is why these terms must be applied and weighed on the basis of the judgement of the appropriate responsible authority, using consultation of those directly involved in the local situation as input. The conceptual model is not suitable to provide an established mechanism for quantifying the impact of these matters. It does, however, provide a structure to make judgments made on the local level transparent, and a method of incorporating these judgements in the overall quantitative odour impact assessment.

The result of the hard assessment of annoyance potential can either be a parameter with a value on a continuous scale (linked to intensity, hedonic tone or an annoyance potential scale) or its result could be expressed as an odour belonging to one of a discreet number of categories (3, 4 or 5) by using a comparative method, in which the odour in question is compared with a discrete number of reference odours. The required methodology is currently being developed. Existing methodology and data (hedonic tone, ranking) can provide a useful and applicable approximation.

In practice, the hard quantitative assessment would use exposure criteria derived from epidemiological data, such as those discussed in chapter 7. For example, an exposure criterion of $C_{98,\ 1\text{-hour}} \leq 1.5\ ou_E{\cdot}m^{-3}$ could be set for odours with high annoyance potential. Appropriate levels of 'equivalent annoyance' could be set for odours with lower annoyance potential on the basis of epidemiological research or laboratory research. Such a set of criteria (expressed in $ou_E{\cdot}m^{-3}$ or dB_{od}) would look like the following example:

Odour Annoyance Potential	Criterion $C_{98,\ 1\text{-hour}} \leq x\ ou_E{\cdot}m^{-3}$	Alternative criterion $C_{98,\ 1\text{-hour}} \leq x\ dB_{od}$
High	$C_{98,\ 1\text{-hour}} \leq 1.5\ ou_E{\cdot}m^{-3}$	$C_{98,\ 1\text{-hour}} \leq 2\ dB_{od}$
Medium	$C_{98,\ 1\text{-hour}} \leq 3\ ou_E{\cdot}m^{-3}$	$C_{98,\ 1\text{-hour}} \leq 5\ dB_{od}$
Low	$C_{98,\ 1\text{-hour}} \leq 6\ ou_E{\cdot}m^{-3}$	$C_{98,\ 1\text{-hour}} \leq 8\ dB_{od}$

For the 'soft' assessment on the basis of identified qualitative risk factors, a two-step assessment can be applied:

- **Step 1: Determine direction of effect**
  A value of +1 indicates that the factor's influence would result in a more lenient assessment of the odour impact. A value of –1 would cause a correction resulting in a more restrictive assessment.
- **Step 2: Apply weighting factor**.
  A weighting factor, with a value between, for example, 0 and 1, would be applied to further take into account the magnitude of the influence of the risk factor on the assessment of odour nuisance potential. It would be feasible to determine weighting factors on the basis of assessment by the local authority, or by consultation with the parties involved in the actual exposure situation. A default set of weighting factors could be proposed in an EA suggested method, to reflect current knowledge on the impact of the factors involved. Such a default set of weighting factors could be adapted periodically to reflect updates prompted by advances in available relevant expertise.

Examples of risk factors that could be incorporated in the ‘soft’ part of the odour impact assessment are:

1) Nuisance sensitivity factors
   a) Perceived health status
   b) History of anxiety over health effects
   c) History of involvement of population in the economic activity of the source
   d) Etc.

2) Context factors
   a) Rural odour in urban context
   b) Industrial odour in rural context
   c) Recreational or landscape value of the location
   d) Etc.

3) Miscellaneous factors
   a) Major employer in the region
   b) Historical source in the location
   c) Degree of BATNEEC compliance
   d) General environmental benefit or impact of activity
   e) Risk of incidental emissions
   f) Duration of impacting activities
   g) Etc.

On the basis of this conceptual model, the combination of hard measurements characterising annoyance potential and soft risk factors to characterise nuisance sensitivity and context can be used in an operational model to assess and predict odour impact in terms of nuisance potential. As a result of this assessment, a site specific exposure criterion can be set, in the familiar terms of calculated odour exposure expressed as a percentile of hourly values combined with an odour concentration, e.g. $C_{98,\ 1\text{-hour}} \leq x$ $ou_E{\cdot}m^{-3}$. For a specific situation, this can be made more operational by using this criterion as the basis for emission limits from identified sources. The conceptual model is illustrated in the diagram in Figure 24.

Figure 24 Diagram representing the conceptual model for odour impact assessment based on odour annoyance potential.

C_{98} dB_{od}	C_{98} ou_E/m^3	Direction	Weight		no.
4.8	3.0	Criterion determined by Annoyance Potential (hard)			
4.8	3.0			**NUISANCE SENSITIVITY**	0
4.3	2.7	-1	0.5	NS1: Percieved Health	1
3.2	2.1	-1	1	NS2: Health effect anxiety	2
3.2	2.1	+1	0	NS3:	3
3.2	2.1	-1	0	NS4	4
3.2	2.1	-1	0	NS5	5
3.2	2.1			**CONTEXT**	6
2.8	1.9	-1	0.3	CXT1 Chemical process in rural area	7
2.8	1.9	+1	0	CXT2	8
2.8	1.9	+1	0	CXT3	9
2.8	1.9	+1	0	CXT4	10
2.8	1.9	-1	0	CXT5	11
2.8	1.9			**MISCELLANEOUS**	12
3.2	2.1	+1	0.3	MIS1 Major employer in area	13
3.2	2.1	-1	0	MIS2	14
3.2	2.1	+1	0	MIS3	15
3.2	2.1	-1	0	MIS4	16
3.2	2.1	+1	0	MIS5	17
3.2	**2.1**	**End result after 'soft' correction**			

8. RESEARCH REQUIRED TO IMPROVE THE QUALITY OF REGULATORY DECISION MAKING ON ODOUR IMPACT

To implement a conceptual model as proposed above, additional data would be required.

The crucial elements would be:

1. Confirmation of dose-effect relationships for the UK situation.
2. Identification of a standard set of quantitative risk factors, and the direction and (maximum) weighting factor for application within the conceptual model.
3. Comparison of the results from existing studies abroad for similar odours can yield useful additional information on relative odour annoyance from different sources.
4. Establishing a rank order for annoyance potential, based on UK data. Such data can be established by interviewing Environmental Health Officers with odour experience, or by comparative testing in laboratory conditions.
5. Setting limit and target values for odour exposure associated with levels of annoyance that are considered acceptable, on the basis of the outcome of research as described in the previous points.
6. Establish levels of equivalent annoyance for odours with different annoyance potential.

At a later stage improvements could be introduced by:

1. Introduction and validation of a standard method for quantitative measurement of odour annoyance, that is currently being developed (Netherlands).
2. Research into factors that can contribute to characterising nuisance sensitivity in a particular population.
3. Research aimed at improving exposure characterisation by using improved short term models or peak to mean estimates by application and validation in dose-effect studies as mentioned above.

9. CONCLUSIONS

The main conclusions of this report are listed below:

1) The process leading from odour formation to annoyance to nuisance is complex, involving many parameters that influence the outcome: annoyance.

2) Cognitive appraisal and psychological coping strategy plays an important role in the determining whether nuisance will develop.

3) A full deterministic model of all factors affecting the occurrence of nuisance is not within reach as yet. It is therefore necessary to regard the most important factors relating cause and effect, and find relevant correlations in a pragmatic, empirical model.

4) Therefore, air quality limits must be formulated on the basis of epidemiological studies describing the relationship between dose and effect.

5) Odour exposure can be characterised using measurement at source combined with dispersion modelling. Methods for characterising odour exposure are reasonably well established:
    a) Standardised methods for measuring odour concentration and emission rates are well established, and their intrinsic uncertainty is known.
    b) Methods to refine odour emission measurement by adding a correction factor are available (intensity, hedonic tone). An overall method to characterise annoyance potential is currently being developed, expected to become available at the end of 2001.
    c) A classification for annoyance potential can be made available relatively quickly using simple survey based ranking.
    d) Dispersion models have considerable limitations, but can be used to characterise odour exposure in terms of probability of exposure over a certain hourly concentration over long periods of time (3-5 years).

6) The effect in terms of changes in behaviour indicating annoyance caused by odour exposure can be detected using questionnaire survey techniques.

7) The relationship between calculated odour exposure and percentage of people annoyed as measured by survey in a population is strong and has been experimentally confirmed in well over a dozen studies in the Netherlands and Germany.

8) A level of 10% of the population annoyed can be clearly and reliably detected, with good statistical confidence that the measured effect is not the result of methodological error

9) Therefore an annoyance level of 10% measured by survey is a good indicator that odour exposure causes a behavioural effect.

10) An odour exposure level associated with a just measurable behavioural effect is a good scientific starting point for setting air quality criteria for odour exposure. The actual levels of such criteria need to be set as a matter of policy, taking into account the priorities and aspirations of a particular society at a particular stage in its history.

11) Available epidemiological data suggest that a behavioural effect of 10% annoyance is associated with odour exposure of $C_{98,\ 1\text{-hour}} = 1.5\ ou_E{\cdot}m^{-3}$ for an odour with relatively high annoyance potential. This exposure level is indicative for measurable odour annoyance in the general public, for an odour with a relatively high annoyance potential (pig production odour). It can be used as a starting point for determining a target value for managing exposure to environmental odours.

12) For a population accustomed to exposure from that odour, from a multitude of sources in the residential environment, an exposure of $C_{98,\ 1\text{-hour}} = 3\ ou_E{\cdot}m^{-3}$ to an odour with relatively high annoyance potential is associated with a clearly measurable behavioural effect as a result of odour exposure. This value can be considered as a starting point for setting a limit value for managing exposure to environmental odours.

13) For a specifically tolerant sample of the population, of those directly involved in business associated with production of odours, a clearly measurable behavioural effect of 10% annoyance is associated with an exposure to $C_{98,\ 1\text{-hour}} = 13\ ou_E{\cdot}m^{-3}$. In separate studies for a dozen agricultural and industrial odours an effect of 10% of the exposed population experiencing '*serious annoyance'* was demonstrated to be associated with an exposure of $C_{98,\ 1\text{-hour}} = 5\ ou_E{\cdot}m^{-3}$. This would indicate that an upper limit to acceptable exposure to odours with high annoyance potential to lie in the range of $5\ ou_E{\cdot}m^{-3} < C_{98,\ 1\text{-hour}} < 13\ ou_E{\cdot}m^{-3}$

14) A correction factor to differentiate air quality criteria for odours with high, medium or low annoyance potential is justified. The effect of such a factor is not expected to be more than a factor 5 to (at most) 10 as expressed in $C_{98,\ 1\text{-hour}}$ concentration levels in $ou_E{\cdot}m^{-3}$.

15) Setting limit and target values for odour exposure for regulatory use is a matter of policy. Science can provide an exposure level associated with a behavioural annoyance effect that can just be detected, with high statistical significance. An exposure level associated with acceptable annoyance should reflect the priorities and aspirations of society. To determine a level that reflects consensus is a matter of policy.

16) As the notion of 'acceptable annoyance level' may change with time, regular reviews of policy are required, taking into account perceived effectiveness of policy and updated epidemiological information.

17) Exposure levels currently associated in the UK with the legal objective of avoiding nuisance, such as $C_{98,\ 1\text{-hour}} < 5\ ou_E{\cdot}m^{-3}$ appear to be relatively lenient relative to the results of dose effect studies in other Northern European countries.

18) Epidemiological dose effect data relationship odour exposure and annoyance for UK conditions would be very welcome as a starting point for setting environmental quality objectives for odour exposure.

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ANNEX A
OVERVIEW OF ODOUR POLICY DEVELOPMENT IN OTHER COUNTRIES

Laws and regulations aimed at limiting the occurrence of nuisance have been in force in many countries for a significant lengths of time. However, regulations aimed specifically at regulating odour-induced annoyance are a more modern feature. The first odour regulations in Europe started to appear in the 1970's, typically defining minimum setback distances for agricultural livestock operations (van Harreveld, 1991, Mahin, 2001). In recent years many states and nations have proposed and, in some cases, implemented policy and regulations specifically aimed at regulating the impact of odours from commercial activities, both agricultural and industrial.

In general terms, there are three basic approaches to regulating odours:

1) Qualitative regulatory frameworks, that define environmental quality in general terms, such as
    a) absence of nuisance,
    b) odours not detrimental to the amenity,
    c) no justified complaints, as judged by officials
    d) etc.

2) Quantitative regulatory frameworks, that define ambient air quality criteria. Such criteria may use:
    a) odour concentration, usually determined as a frequency of exceedance of concentration limits as determined using dispersion modelling,
    b) ambient concentration limits of specific odorous compounds (e.g. hydrogen sulphide)
    c) Frequency of detection of odours using field panels.

3) Standard operational requirements for specific activities, such as:
    a) Setback distances for livestock housing units
    b) Requirements for standard abatement techniques (i.e. defined using concepts similar to BATNEEC) combined with minimum setback distances at different production capacity levels, applied to specific industrial or agricultural activities.

In the following sections different approaches that are in place or have been proposed are identified and described. An overview of the current regulatory legislation in the United Kingdom is provided in a separate Annex B.

A.1. The Netherlands

Odour regulation has a long history in the Netherlands, where 16 million active and relatively wealthy residents have to find a balance between living, working, transport, recreation and a sizeable industry and agriculture sector (van Harreveld, 1991).

Currently, there are two discrete regulatory frameworks for treatment of agricultural odours and odours associated with industrial activities. These frameworks are discussed below:

A.1.1. Odour regulation for livestock odours

The earliest specific regulations for odours were aimed at regulating the odours from the livestock production sector, with an emphasis on pig odours. The annual production is approx. 30 million pigs, which amounts to 2 pigs per head of the population. There are 1.4 million places for sows and 7.4 million places for finishers in Dutch pig houses (1998).

The first guideline on how to take account of environmental odour aspects for licensing as a result of application of the existing Nuisance Law was issued in 1971, and revised several times in later years: 1984 and 1996.

The successive guideline documents are:

- *Brochure Livestock rearing and nuisance law* (1976)
- *Guidance note on the application of the Nuisance Law on livestock production units* (1984)
- *Brochure Livestock production and Nuisance Law* (1985)
- *Assessment of accumulation by intensive livestock production*, Publication Series Air no. 46, Ministry of Public Planning and the Environment (1985)
- *Guideline Livestock production and Odour Annoyance* (1996)

Currently, the Guideline Livestock production and Odour Annoyance (1996) is used. The main instrument for managing odour impact through licensing has been retained in all these successive guidelines, in the form of a graph relating the required setback distances to the number of animals in the pig production unit, see Figure 25.

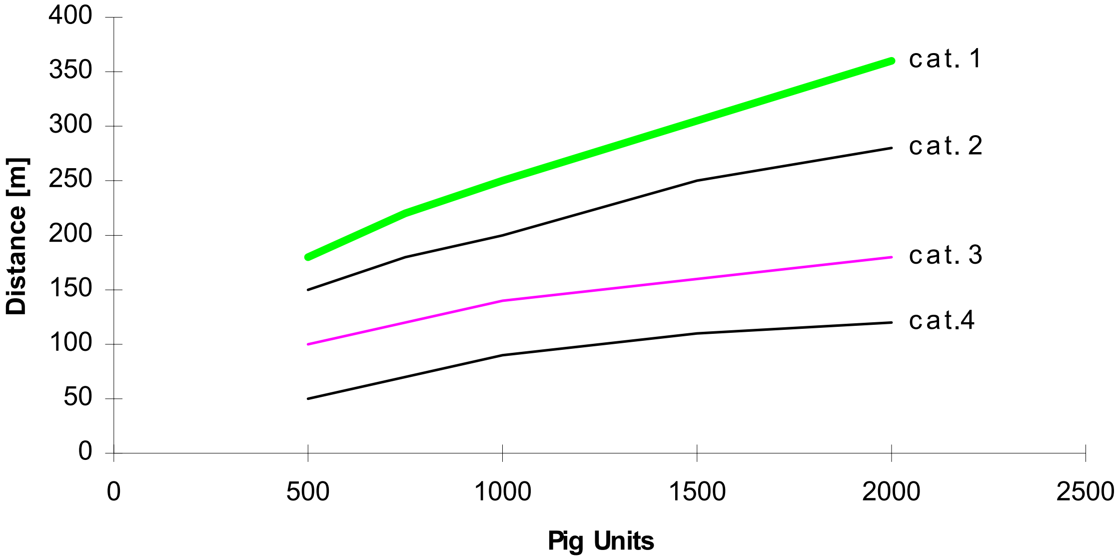

Figure 25 Setback distances for pig production units in the Netherlands, 500 to 2500 pig units (equivalent to fatteners), Brochure Hinderwet en Veehouderij, 1996

The 'distance graph' has remained largely the same over the years. In 1996 the lines were extended for higher numbers of pigs. The main drive behind the 1996 revision was to find ways to allow further expansion of pig units that had reached the limits of their expansion possibilities. Although the 'distance graph' remained largely unchanged, the interpretation of the categories and the method of measuring distances between buildings and residences was adapted to allow some degree of further expansion, while maintaining the objective that no '*severe odour nuisance*' should occur. Another modification concerned the conversion for various animals and life stages to '*mestvarken eenheden*' (mve units, giving the equivalent to the emission of one finisher pig). The tables were expanded to include values for low emission housing, the certified 'Green Label' housing systems. Using the expanded table for these 'Green Label' systems allowed existing pig units to expand, providing that they used these low emission housing systems.

In 1997 and 1998 a number of rulings of the Council of State, the highest appeal court for planning cases challenged parts of the revisions of 1996. Particularly the modifications in the application of the categories, that implied that a number of categories of residences were moved to a less protected category, was not accepted. The Council of State judged the motivation for the revisions insufficient. As a result, the Ministry of Public Planning and the Environment has started a number of research projects, to establish the scientific basis for the relation between exposure to pig odours and actual levels of annoyance. A second project involves the measurement of emission factors for different life stages of pigs. The results will be used as the starting point for a major policy review, named *Revision of policy instruments for rural odour policy*, with the Dutch acronym VIAS. The review is currently ongoing and is expected to lead to introduction of a fully revised guideline in autumn 2000 or early in 2001.

It is expected that the 'distance graph' will continue to be applied, but the use of four categories of land use may be simplified and adapted to reflect the results of the dose-effect studies. In addition, a revision of the conversion factors to [mve] for different life stages is expected to be revised, on the basis of recently measured values.

A.1.2. Odour regulations for industrial odours

The basis of the Dutch policy on industrial odours is the First National Plan for the Environment or NMP-1 (VROM, 1988) in which specific targets are set:

- VROM, (1988) *Nationaal Milieubeleidsplan I (NMP 1, English: National Environment Plan)*, Ministry of Public Housing, Planning and the Environment, The Hague, The Netherlands.

The target for objectives A75 and S37 in the NMP-1 was to reduce the number of residential dwellings 'affected by odour exposure' to less than 750 000 by the year 2000. This target was based on an assessment of what could be achieved by applying odour control 'at source'. In the review of NMP-1, the National Survey of the Environment (Langeweg, 1998), this target was translated into reducing the number of residents affected by odour annoyance to '12% of the population', which implies that a degree of impact to 12% of the population or less was deemed acceptable.

These general policy targets have been used as the basis for a succession of operational regulations and guidelines. As early as 1984, a guideline was published by the Ministry VROM that set stringent air quality targets for odour, based on limits for exposure calculated as a percentile of 1-hourly concentrations, using a national regulatory dispersion model (the LTFD model):

- VROM, (1984) *Lucht indicatief meerjaren progamma lucht 1985-1989 (English: Indicative Long-Term Programme for Air Quality 1985-1989)*, Ministry VROM, The Hague, Netherlands, ISBN 90 12 04764 1.

The input for the model was to be provided by source emission measurements, using olfactometry. Air quality criteria were defined, as a limit for the 1-hour average odour concentration that could not be exceeded more than a defined percentage of annual hours.

This is the x $ou_E \cdot m^{-3}$ as a y% percentile for hourly averages criterion. The following limits were proposed and later implemented in hundreds of licence applications:

- $C_{99.5,\ 1\text{-hour}} < 0.5\ ou_E \cdot m^{-3}$ for applications for new installations (sources), not to be exceeded at the nearest 'odour sensitive location' (e.g. residential property, schools, hospitals, recreational housing etc.)
- $C_{98,\ 1\text{-hour}} < 0.5\ ou_E \cdot m^{-3}$ for applications for existing installations (sources) or expansion of such installations, not to be exceeded at the nearest 'odour sensitive location' (e.g. residential property, schools, hospitals, recreational housing etc.)
- $C_{95,\ 1\text{-hour}} < 0.5\ ou_E \cdot m^{-3}$ for isolated residential houses located on industrial estates
- $C_{99.9,\ 1\text{-hour}} < 0.5\ ou_E \cdot m^{-3}$ for discontinuous, incidental sources, not to be exceeded at the nearest 'odour sensitive location' (e.g. residential property, schools, hospitals, recreational housing etc.) Examples of such sources are loading/unloading operations, cleaning and opening of reactor vessels etc. that may lead to short but high impact emissions, during for example 0.5 hour every two weeks.

The regulators and the courts of appeal enthusiastically applied this guideline, as it assisted in reducing the emphasis on ambiguous judgments on the magnitude of the perceived nuisance of individual residents.

As a result of this guideline, the requirement for standardised, reproducible measurements became obvious, and resulted in a considerable effort to produce a standard for olfactometry, which was implemented in NVN2820:1993. Laboratories were then required to become accredited and the measurements were included as a method for impact assessment for licensing purposes and enforcement. (Note: The value of $0.5\ ou_E \cdot m^{-3}$, referenced to 40 ppb/v n-butanol, is equal to $1\ ge \cdot m^{-3}$ or Dutch odour unit, that was referenced to 20 ppb/v n-butanol.).

In May 1994 the Minister responsible for the Environment published The Revised Odour Policy guideline document. After discussing the document in Parliament, the Minister reconsidered and decided to abandon the strict air quality target approach of this document. The main argument was that, using common sense, it could not be right to apply the same air quality criterion, based on odour concentration, for odours as different in their potential to cause annoyance as bakeries and rendering plants.

This political development coincided with a more general policy shift in which the responsibility for environmental licensing was removed from the National ministry, by giving considerably more responsibilities to the Provincial and Municipal authorities.

The Minister outlined the policy shift in a letter to all Provincial Councils and Municipal Executive Councils dated June 30th, 1995, that has since become the key policy document for odours (Infomil, 2000).

The letter outlines the following principles to be used in the licensing process:

- If there is no existing annoyance, no odour impact reducing measures are required
- If there is annoyance, odour impact reduction measures have to be put in place on the principle of ALARA (As Low As Reasonably Achievable)
- The *level of annoyance* can be assessed using a number of methods, including survey methods (see section 0 5.2.2 Standardised Telephone Survey of the Living Environment: TLO), complaints registration etc. For a number of defined sectors of

industries (Category I processes) the *acceptable level of annoyance* is an issue contained in specific odour impact study documents.

- The *admissible level of odour annoyance* is to be determined by the responsible authority (i.e. provincial or municipal authorities, depending on the type of industrial activity).

The thinking behind the new approach is encapsulated in the distinction between two key concepts, first published in the NeR (Infomil, 2000):

- **Admissible annoyance level** (Acceptabel hinderniveau)
  Criterion to be used in licensing, that is applied as national policy after 1995 as defined in the NeR, first published in 1996 (Infomil, 2000). The degree of annoyance that is admissible, as determined by the responsible authority. It is the overall result of an assessment that includes the following aspects: the history of the installation in its environment, the nature and appraisal of the odour, the complaints, additional information on the annoyance caused and (possible) emissions, technical and financial consequences of possible abatement measures, consequences for employment, etc. (letter on odour policy by the Minister responsible for the environment, 30 June 1995). The admissible annoyance level is based on an environmental indication, qualification and/or quantification of annoyance level and an assessment and judgment of what is admissible taking into account local circumstances including aspects of public planning, social economic and financial/commercial factors (NeR, Infomil, 2000).

- **Acceptable annoyance level** (Aanvaardbaar hinderniveau)
  Concept that forms a part of the admissible annoyance level, based on environmental indication, that does not include consideration of technical, financial, social-economic or public planning aspects (NeR, Infomil, 2000).

The Ministry did publish an overview of 'suitable methods' for assessing annoyance levels (see Table 8), but failed to provide an operational guideline to apply the 'admissible level of odour annoyance' concept.

Nature of method	Preferred	Applicable
Indicative	*Signal* + Complaint registration + Complaint analysis + Consultation of the public *Background* + Benchmark of similar situations + Literature *Field observation* + Personal observation	*Community annoyance* + Hedonic scale *Odour exposure* + Selecting a particular exposure criterion
Qualitative	*Signal* + Complaints analysis Community Annoyance + community panel + annoyance surveys (TLO) *Combined methods* + Field panels and complaints analysis *Odour exposure* + Emission measurements and dispersion modelling	*Background information* + Benchmark of similar situations *Field observation* + Personal observation + Field panels *Odour exposure* + Hedonic scale + Selecting a particular exposure criterion
Quantitative	*Combined methods* + Field panels with hedonic scale + Emission measurements at sources and dispersion modeling combined with: - hedonic scale - Annoyance surveys (TLO) - acceptable exposure data from similar situations odour annoyance perception survey	*Signal* + Complaints analysis *Field observation* + Annoyance perception survey +Annoyance survey (TLO) *Odour exposure* + Emission measurements at sources and dispersion modeling

Table 8 Methods for assessing odour impact as suggested in 1996 by the Ministry for Public Planning, Housing and the Environment, The Netherlands, NeR, Infomil 2000.

The air quality criterion of $C_{98,\ 1\text{-hour}} < 5\ ou_E{\cdot}m^{-3}$, that had previously been proposed as an upper limit value, was mentioned in the letter, but as a ‘calculation value’ for assessing existing sources only. The concept of setting a national upper limit value for exposure to odour was abandoned. The letter emphasizes that odour exposure criteria will be used as a means to evaluate different odour management scenarios to assess the effectiveness of ALARA odour control rather than as a general target value for air quality in the licensing process.

The letter referred to the Netherlands Emissions Guideline as the source where Category-I industry studies would be made available. The NeR of 1996, that was updated in 2000, contains these industry specific studies:

- Infomil, (1996) *NeR Nederlandse Emissie Richtlijn, Hindersystematiek Geur. (Netherlands Emissions Guideline. Framework for odour nuisance)*, 1996, ISBN 90 76323 01 1
- Infomil, (2000) *NeR Nederlandse Emissie Richtlijn. (Netherlands Emissions Guideline)*, 2000, ISBN 90 76323 01 1.

The Category-I industries for which studies were carried out and agreed with the relevant industry associations are:

1) Composting of green waste
2) Potato processing industries
3) Meat packing and processing
4) Biscuit and pastry producing industry
5) Leather and tanning industry
6) Cocoa processing
7) Beer breweries
8) Composting of organic waste fraction (GFT)
9) Large bakeries and bread producers
10) Flavour and Fragrance industry
11) Asphalt production
12) Wastewater treatment works
13) Animal feed processing
14) Grass drying installations
15) Coffee roasting industries
16) Milk processing

In the National Emissions Guideline, specific chapters were included for sectors of industry known to cause odour annoyance. Each chapter that defined benchmarks for odour emissions, provided a Best Available Technique guidance, and in a number of cases defined ‘calculation values’ for odour exposure, in the well-known format of a concentration limit for the 98-percentile of 1-hourly calculated concentrations. These ‘calculation values’ were adopted in most cases, at least as a starting point, in licensing. For licence applications where such guidance was not available, alternative approaches were proposed by applicants and their advisors, or by provincial or municipal authorities.

Industry specific odour exposure criteria, Netherlands, NeR, 2000			
	Target $C_{98,\ 1hour}$ ou_E/m^3	Limit $C_{98,\ 1hour}$ ou_E/m^3	
Bakeries/ bread			No limit value, >>10 ou_E/m^3 98-p
Bakeries/ pastry	5		
Breweries > 200 000 hectolitre		1.5	Target value for existing sites
Slaughterhouses	0.55	1.5	
Meat processing	0.95	2.5	
Grass dryers		2.5	
Coffee roasters		3.5	
Animal feed production		1	
Flavours and fragrances	2	3.5	
Green waste composting			Distance table for buffer zones
GFT composting, new facility	0.5	1.5	
GFT composting, existing facility	1.5	3.0	
Waste water treatment (domestic), new		0.5	for urban domestic residences
Waste water treatment (domestic), new		1.5	for rural areas or commercial sites
Waste water treatment (domestic), existing		1.0	for urban domestic residences
Waste water treatment (domestic), existing		3.5	for rural areas or commercial sites

Table 9 Calculation values for acceptable exposure to odours for specific industries in the Netherlands. Source: NeR, 2000

In some cases, the operational air quality criterion for a licence application was derived from measurements that provide a measure of ‘annoyance potential, e.g. hedonic tone, intensity or comparative annoyance potential measurements.

Although the room to manoeuvre that was provided was considered in a positive light by those involved in the licensing process, it also led to considerably more uncertainty and discussion, which led in many cases to extensive negotiation between applicants and licensing authorities. Consequently, the risk of local and regional differences in environmental quality standards became a concern.

The technical commission advising on Environmental Impact Statements signalled in 1997 that insufficient consensus existed for the practical application of the current approach to establish an ‘acceptable level of annoyance’ As a result the Netherlands Standardisation Organisation NEN have advised to develop a method for quantitative assessment of ‘annoyance potential. A feasibility study was completed in early 2000, which concluded that a method for ‘annoyance potential as an attribute of odour could be developed and combined in a model that combined ‘hard’ assessments of odour concentration and odour annoyance and ‘soft’ risk assessments to arrive at a transparent assessment of ‘acceptable annoyance level. A similar conceptual framework is proposed in this report.

Once a standardised method for odour potential measurement is available, (final report planned for completion by the end of 2001), this is expected to lead to a review of policy, which may cause the pendulum to swing towards a slightly less flexible, more defined guideline.

It should be noted that in the typical 'consensus culture' of the Netherlands, the values that have been proposed in the NeR document for Category I industries, as shown in Table are generally applied without much deviation.

A.2. Germany

The law concerning air quality issues in Germany is the Bundesimmissionsschutz Gesetz (known as 'BimSchG'), or the Federal Immission Control act of 1990, which is available in English from the Ministry for Environment, Nature Conservation and Nuclear Safety.

All odours from any commercial installation are considered an annoyance, according to §3 of 'BimSchG'. For licensing and enforcement, however, the issue is to determine whether the annoyance constitutes a 'significant disturbance', on the basis of the 'relevance of the annoyance'. However, the 'BimSchG' does not provide for criteria to determine when an *annoyance* becomes a *significant disturbance* (nuisance).

The second relevant official regulatory document, aimed at providing technical guidance for specific industries on how to achieve the general principles concerning air quality in the 'BimSchG' also fails to provide operational annoyance criteria. The *Technische Anleitung zur Reinhaltung der Luft*, or *TA-Luft*, details the technical measures, expected to be applied in different sectors of industry and agriculture, including methods for assessment. The *TA-Luft* is available in English:

- *Technical Instruction on Air Quality control* (Erste Allgemeine Verwaltungsvorschrift zum Bundesimmissionsschutzgesetz), Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, Bonn, 1986 (GBBl. P.95)

The *TA-Luft* defines a maximum 'odour frequency', as an ambient air quality characteristic, but does not specify a method to assess this parameter. In 1994 the Department of the Environment of Nordrheinland Westfalen introduced a method for this purpose, aimed at assessing ambient air quality for odours in the vicinity of an existing source. The document is available in English translation:

- *Determination and Evaluation of odour immissions – Odour exposure guideline* (Feststellung und Beurteilung von Geruchsimissionen – Geruchsimmissionsrichtlinie), Länderausschuß für Imissionsschutz, LAI-Schriftenreihe o. 5, Berlin 1994.

This method prescribes a method for long-term field panel observations, in which the fraction of 'odour hours' is determined by a team of assessors on pre-defined locations on a grid around the source in question. The method has been described in a standard:

- VDI3940, (1993) *Determination of Odorants in Ambient Air by Field Inspections*, Beuth Verlag, Düsseldorf, Germany.

This method can be applied to determine licensing applications (Both, 2001).

The exposure criteria are differentiated for areas with different land use:

- < 10% 'odour hours' in residential areas
- < 15% 'odour hours' in industrial areas.

However, in most cases, a technical guideline is applied, that provides detailed advice on the design and operation of the activity of the applicant. An example of such a guideline is:

- VDI3475 Part 1 *Emission reduction for biological waste treatment units - Collection and Composting for units with a capacity ≥ 0.75 Mg/h.* (in German), Beuth Verlag, Düsseldorf, Germany.

A.2.1. Agricultural odour regulation in Germany

For agricultural odours, standards exist describing standard practice and the techniques that are to be applied to limit environmental impact, including odour emissions. These documents are:

- VDI3471:1986 Emission Control. Livestock management – Pigs
- VDI3471:1986 Emission Control. Livestock management – Hens
- VDI3473:1994 Part 1 (draft) Emission Control. Livestock farming – Cattle. Odorants.

In addition to technical guidance on the design and operation of pig units, the technical standard, VDI3471:1986 contains a graph providing setback distances, for pig units of different sizes. This graph is presented in Figure 26. In determining setback distances, operational methods and design of the pig unit are taken into account, using a system of assigning points. A correction on the standard setback distance can be applied on the basis of the total number of points.

Criteria	Points
Waste removal and storage	
Solid manure removal	
'Tiefstall'	60
Mechanical manure removal to storage enclosed by walls on three sides	50
Mechanical manure removal to transport vehicle	40
Mechanical manure removal to open air manure heap	20
Liquid manure removal	
Slatted floors, >45%	10
Slatted floors, <45%	5
Mechanical removal	0
Slurry storage	
Storage tank fully enclosed	50
Storage with cover	30
Storage with full natural crust formed	30
Storage without cover	0
Underfloor storage in the pig house	30
Ventilation	
Summer ventilation rate, according to DIN18910	
Temperature difference ≤ 2 K	10
Temperature difference ≤ 3 K	5
Temperature difference > 3 K	0
Ventilation exit duct	
Vertical, height ≥ 1.5 m above roof apex	15
Vertical, height < 1.5 m above roof apex	5
Horizontal side vents	0
Vertical exit velocity at summer ventilation rate	
Velocity ≥ 12 m/s	25
10 ≤ velocity < 12 m/s	20
7 ≤ velocity < 10 m/s	10
Velocity < 7 m/s	0
Miscellaneous	
Special feeds, dry waste food	0
Kitchen wastes with weak odour	up to –10
Wastes with a strong odour	Up to –25
Location	Up to ± 20
Slurry storage capacity	
≥ 6 months	10
≥ 5 months	5
≥ 4 months	0

Table 10 Correction factors and their points value for use with the setback distance graph, VDI3471

If a pig unit complies with the VDI3471 standard, and is located so that the setback distances are respected, that is in most cases sufficient ground for the local authority to grant a licence. In those cases where the distance to residences is less than 100m, or in cases where the setback distances cannot be attained fully, expert advice is sought to determine the application, using detailed assessments, typically based on atmospheric dispersion modelling.

A.2.2. The distance graph in VDI3471

The capacity of a pig unit is expressed in 'Grossvieheinheiten' (GV), that are equivalent to 500 kg live weight.

Once the number of GV units has been determined, a point system is applied to take design and operational practice into account. The point system is summarised in Table . Different curves on the distance graph are used, depending on the number of points.

Note that the graph only goes up to 650 livestock units (500 kg live weight).

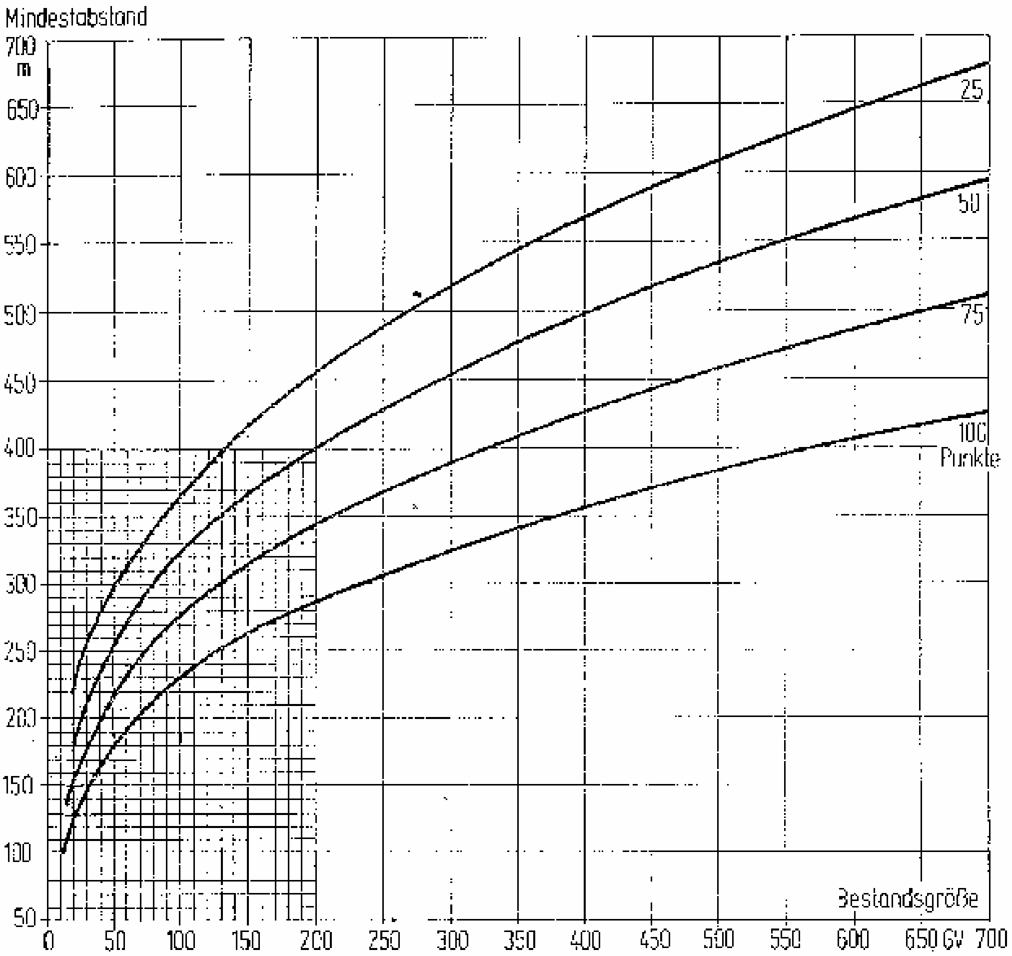

Figure 26 Setback distances graph, for different numbers of 'Livestock Units' (GV, equivalent to 500 kg live weight), wit correction based on points for operational practice and design of the pig unit. Germany, VDI3471. One sow on an integrated unit in Ireland is approximately equivalent to 1.3 GV.

A.3. Belgium

Currently a policy review is under way to establish a concerted policy on odours in Flanders, the Northern part of Belgium. The *Flemish Environmental Policy Plan 2002-2006* contains an initiative to define odour exposure standards for 16 sectors of economic activity.

This will be done using a methodology recently used to in a long term research programme looking at dose effect relations, focussing on five pilot sectors of economic activity:

- Pig farms
- Slaughterhouses
- Paint application
- Wastewater treatment plants
- Textile plants

The techniques rely on field panels that determine the maximum distance at which the source can be detected. This distance and the weather conditions during the field test are then used as input in a Gaussian dispersion model to estimate the emission of the source in 'sniffing units'. The concept of 'sniffing unit' is similar in use to odour units, but measured in the field rather than in the laboratory, using stack samples, as is done for odour units. (Van Broeck e.a., 2001).

The calculated emission in sniffing units is then used in dispersion modelling to determine percentiles of 1 hourly calculated odour concentrations in sniffing units.

Intermediate results have been reported recently in:

- Van Broeck, G., Van Langenhove, H, Nieuwejaers, B., (2001) *Recent odour regulation developments in Flanders: Ambient odour quality standards based on dose-response relationships*, In: Proceedings of the 1st IWA International Conference on Odour and VOC's: Measurement, Regulation and Control Techniques, University of New South Wales, Sydney, March 25-28, 2001, ed. J. Jiang, International Water Association, ISBN 0 7 334 1769 8.

In this report, the authors reported finding significant correlations between odour exposure and surveyed annoyance in all of the 16 study locations. The background percentage of annoyance varied between 0% and 15%. For three sectors a ';no effect level' was established:

- Slaughterhouses: 0.5 sniffing units as a 98th percentile of hourly calculated odour concentration
- Paint spraying facilities: 2.0 sniffing units as a 98th percentile of hourly calculated odour concentration
- Wastewater treatment plants: 0.5 sniffing units as a 98th percentile of hourly calculated odour concentration.

For pig production units and textile plants no unambiguous 'no effect level' was reported.

A.4. Denmark

In Denmark an exposure criterion is used which stated that the ground level concentration should not exceed 5 to 10 $ou \cdot m^{-3}$, depending on the location (residential or non-residential), at a 99-percentile, with an averaging time of 1 minute.

A.5. New Zealand

New Zealand's Resource Management Act 1991 imposes a duty upon industry to avoid causing "objectionable" or "offensive" odours to such an extent that they are likely to have adverse environmental effects.

Since 1995 New Zealand has a guideline for managing odour to make this general legal requirement operational: the *Odour Management under the Resource Management Act (1995)*

Most regional authorities however propose guidelines in more general common law terms: *No objectionable odour at or beyond the property (site) boundary.*

Most Regional Air Plans do not currently recommend a specific odour modelling guideline. and prefer to put narrative rules in their Plans, including the following typical statement regarding selection of odour modelling guideline:
"Activities will be assessed having regard to the following matters: ... Whether the activity complies with the relevant national regulations, standards and codes of practice"(Source: Revised Proposed Regional Air Quality Plan for Northland, 16 May 1998).

At the time of writing this report, the only examples of full or partial odour modelling guidelines mentioned in Regional Air Plans in New Zealand are found in the Waikato and Otago Regional Council, summarised below.

Otago

Schedule 1.7 of the Proposed Regional Air Plan (February 1998) describes dispersion modelling procedures, and recommends using the 99.5 percentile of real meteorological data for assessment of effects. However, the Schedule does not recommend a concentration component to the odour modeling guideline, instead advising the applicant to consult the Regional Council to determine an appropriate guideline.

Waikato

Section 6.4.1.2 of the Proposed Waikato Regional Plan (September 1998) contains a section on modelling guidelines for determining "acceptable" odour for resource consent applications. The Plan takes care to emphasise that this is not a modelling guideline and should not be used or quoted as such; rather, it is a guide in assessing resource consent applications. Further, the guideline is applicable primarily to assessing new activities, but may also apply to existing activities as appropriate. The guideline is:

"One hour average concentrations of odour, as predicted by an ISC-type atmospheric dispersion model, should not exceed 5 OU/m^{3} *divided by the appropriate peak to mean ratio for more than 0.1% of the time. Odour emission concentrations (and rates) used in the ISC-type model shall be based on certainty-based forced-choice olfactometry."*

The recommended P/M ratios are derived from the New South Wales (Australia) draft guideline (2001). The specific ratios recommended by the Waikato Regional Council (WRC) are shown in Table 1 on this page.

Source type	Receptor location	
	x < 1000m	***x > 1000m***
Area	***1.5***	***2***
Line	***6***	***6***
Point on the surface	***25***	***7***
Tall stack	***20***	***6***
Wake affected point source	***2.5***	***-***

Table 11 Recommended peak-to-mean ratio's, New Zealand.

In the event that a full meteorological data set is not available, and screening data is used instead, then the above guideline is still applied but to 100% of the model predictions.

In spite of the relatively vague approach by the regional authorities, air quality criteria in the form of odour exposure limits are used in some cases:

- A $C_{99,\ 1\text{-hour}} \leq 2\ \mathrm{ou \cdot m^{-3}}$ as a 1-hour average was applied by the Auckland Regional Council to the Mangere Sewage Treatment Plant, Manukau City
- Southland Regional Council requires a maximum 3-minute odour concentration beyond the site boundary of 0.3 ou/m^{3}. The Canterbury Regional Council has also used similar guidelines when assessing air consent applications.

In a recent report, commissioned by Auckland Regional Council and co-funded by the Ministry of the Environment of New Zealand, quantitative air quality criteria are suggested, of 5 to 10 $\mathrm{ou_E \cdot m^{-3}}$ at percentile values of 99.5 to 99.9. The full report is available on the Ministry website http://www.mfe.govt.nz and is titled:

- Freeman, T., Needham, C. Schulz, T., (2000) *Analysis of Options for Odour Evaluation for Industrial or Trade Processes.* CH2M-Beca for Auckland Regional Council.

The Ministry of the Environment has started a review of the guide to *Odour Management under the Resource Management Act (1995)*. The review will assess how the guide has been applied, examine the current problems facing odour management in New Zealand and recommend updated guidance for a new guide to odour management.

Matters that are likely to be covered in the revised document are:

- recent case law and best practice toward odour management
- specific criteria for assessing atmospheric dispersion modelling for odour
- the relationship between odour management and land use
- the role of performance standards for odour
- methods for surveying community response
- standard methods for sampling and measurement of odour.

Draft reports are expected to be completed and available for comment by mid 2001.

A.6. Japan

Japan has a long track record in regulating odours. In the 1970's around 20,000 complaints were registered each year. This number has been decreasing from year to year after the introduction of regulations in 1971, but has recently showed a significant increase, caused by increasing complaints against waste burning practices. (OSAKO, Masahiro, Dept. of Waste Management Research, National Institute for Environmental Studies, Japan.).

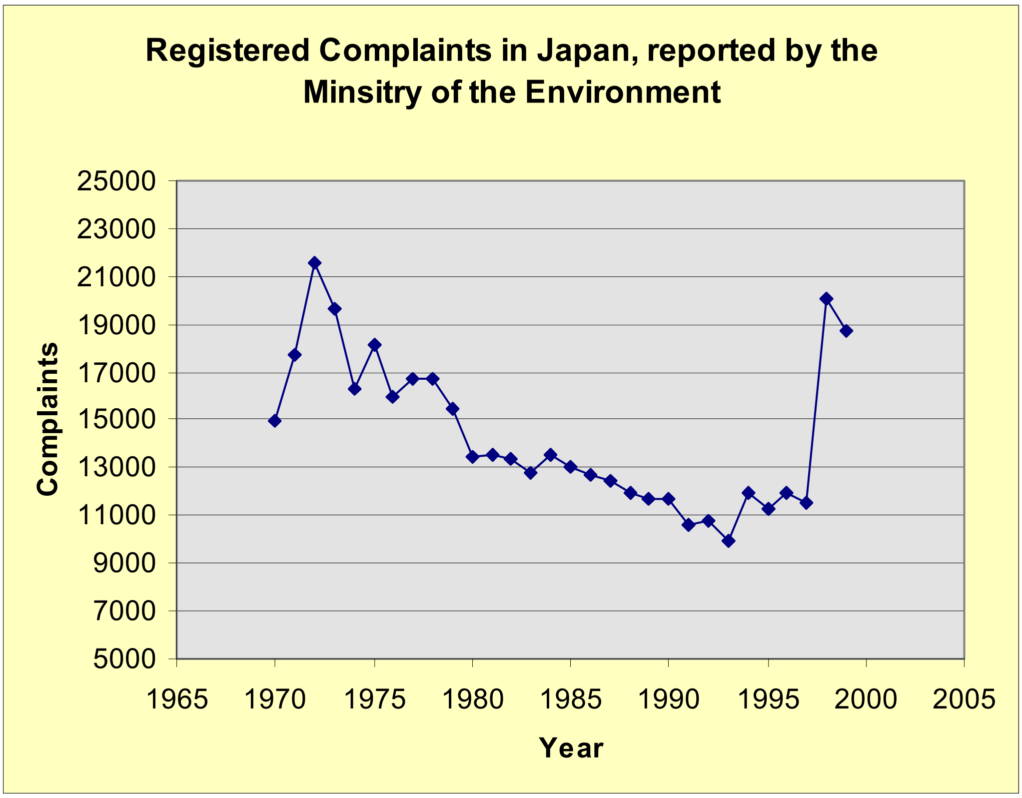

Figure 27 Registered complaints in Japan, 1970-1999. Source: Ministry of the Environment. Japan

In 1971 the first specific odour control regulation was introduced:

- *Offensive Odour Control Law*, Law No. 91 of 1971, amended by Law No. 71 1 June of 1995.

This Law was updated several times, in 1995 and in 1997. The Law applies to designated areas, where emissions are to be regulated. Governors of prefectures determine these areas, after hearing the local (municipal) authorities. Just over half of all municipalities in Japan have designated odour control areas.

The Law as it stands now identifies 22 individual odorous compounds and sets ambient limit values for each of these compounds (see Table).

The Japanese regulation is based on a specific method of olfactometry, based on triangle testing after preparing different dilutions of odour in small disposable sample bags by an injection method. The smells are assessed by selected panel members using a face mask and sniffing directly from the bag through a relatively large diameter glass connector tube. The panel members are selected based on a screening test using 5 chemical compounds, that are assessed in different concentrations using dipsticks and solutions of the odorants in paraffin or propylene glycol. The five selection odorants are: β-phenylethyl alcohol, methyl cyclopentenolone, iso-valeric acid, γ-undecalactone, skatole.

The standard protocol for the Triangle Olfactory Malodour Determination method is accepted as the method of preference for evaluating malodours by 40 of the 47 prefectures of Japan, and has been officially described in Notification No. 238 of the Tokyo Metropolitan Area, March 1977.

The Japanese triangle method for olfactometry yields a result for n-butanol of 38 ppb/v, which is compatible with the accepted reference value for the European odour unit of 40 ppb/v. The Japanese *Offensive Odour Control Law* expresses odour intensity as the Odour Index, which is:

$$\text{Odour Index} = 10 \log(\text{Odour Unit})$$

This is identical in concept and value to the dB_{od}. The standard is based on the premise that an Odour Index associated with an odour intensity scale value of 2.5-3.5 is deemed acceptable.

The intensity scale used is:

- 0 - Not perceptible
- 1 - Faint smell (detectable)
- 2 - Weakly quality perceptible (recognition)
- 3 - Easily quality perceptible
- 4 – strong
- 5 – very strong

The *Offensive Odour Control Law* sets three types of limit values:

- 1st criterion: Maximum concentration at site boundary, maximum ground level concentration or maximum concentration at 1.5 m above liquid surface of wastewater. For this criterion the criteria for 'acceptable' concentrations are set according to the values presented in Table . The actual value is to be determined by the prefectural governor (regional authority).

Odour exposure limit concentrations for 22 regulated odorants, Japan			
Intensity scale value	I = 2.5	I = 3.5	unit
Compound			
Odour Index	10 to 15	14 to 21	
Ammonia	1	5	ppm/v
Hydrogen Sulfide	0.002	0.010	ppm/v
Methyl mercaptane	0.02	0.20	ppm/v
Dimethyl sulphide	0.01	0.20	ppm/v
Dimethyl disulphide	0.009	0.100	ppm/v
Trimethyl amine	0.005	0.070	ppm/v
Acetaldehyde	0.05	0.50	ppm/v
Propionaldehyde	0.05	0.50	ppm/v
n-butylaldehyde	0.009	0.080	ppm/v
Iso-butylaldehyde	0.02	0.20	ppm/v
n-valeraldehyde	0.009	0.050	ppm/v
Iso valeraldehyde	0.003	0.010	ppm/v
Iso-butanol	0.9	20.0	ppm/v
Ethyl acetate	3	20	ppm/v
Methyl isobutyl ketone	1	6	ppm/v
Toluene	10	60	ppm/v
Styrene	0.4	2.0	ppm/v
Xylene	1	5	ppm/v
Proprionic acid	0.03	0.20	ppm/v
n-butanoic acid	0.001	0.006	ppm/v
n-valeric acid	0.0009	0.0040	ppm/v
Iso-valeric acid	0.001	0.010	ppm/v

Table 12 Criteria concentrations equivalent to intensity scale 2.5 and 3.5 for 22 regulated odorous compounds, Japan.

- 2nd criterion: Maximum concentration in a stack emission. This is calculated using simplified dispersion modelling equations, for different types of stacks (heights). The calculation essentially serves to calculate the stack concentration corresponding to the acceptable (maximum) concentration at ground level, as defined in the previous 1st criterion at the site boundary.

- 3rd criterion: for odorous wastewater, based on the dissolved odorant concentration for four sulphur compounds. It uses a simple formula:

$C_{Lm} = k \times C_m$ where C_{Lm} is the regulation standard limit of the odorous substance in a wastewater effluent in mg/lk is a constant from Table , depending on compound and the flow of effluentCm is the criterion concentration for that compound in air, as determined by the appropriate authority within the range given in Table .

Flow of effluent Q	$Q \leq 10^{-3}\ m^3 \cdot s^{-1}$	$10^{-3} < Q \leq 10^{-1}\ m^3 \cdot s^{-1}$	$Q > 10^{-1}\ m^3 \cdot s^{-1}$
Substance	Value for constant *k*		
Hydrogen sulphide	5.6	1.2	0.26
Methyl mercaptan	16	3.4	0.71
Dimethyl sulphide	32	6.9	1.4
Dimethyl disulphide	63	14	2.9

Table 13 Values of constant k for four regulatory compounds to calculate maximum concentration allowed in liquid effluent, Japan.

In addition to a National regulation, regional authorities have issued their own regulations. The Tokyo metropolitan area, with approximately 12 million inhabitants, has its own regulation, in force since 1977, setting limits for odour concentration in stack emissions (odour concentration 300, 500 or 1000 in the stack emission, depending on the land use) and for ambient concentration at the site boundary of 10, 15 and 20. These values appear to be equivalent to $ou_E \cdot m^{-3}$, based on a comparison of the odour threshold for n-butanol.

A.7. Australia

In Australia the states have the responsibility for setting air quality policies for odour. The different states have traditionally taken very individual approaches. Recently there appears to be a trend towards convergence, as is shown in a number of recent draft policies, some of which are discussed below.

A main development supporting the shift from traditionally qualitative odour regulations to quantitative regulations is the development of an Australian standard for odour measurement, that has used the CEN draft EN13725 ‘Air quality – Determination of odour concentration by dynamic olfactometry’ as a starting point. The new Australian Standards document has been developed jointly with New Zealand and is titled:

- draft Australian standard DR 99306 *Air quality - Determination of odour concentration by dynamic olfactometry*

Most Australian states are expected to adopt this standard, with the exception of Victoria, that so far indicates continued use of its own olfactometry method.

The differences between the standards have been estimated in the recent NSW-EPA draft odour policy (see section 0):
Four different dynamic olfactometry methods were considered, as follows:

- V EPA method B2, used in Victoria
- QDEH method 6, Queensland
- NSW EPA/SWB method
- Draft Australian or European CEN standard methods.

To convert odour units from one standard method to another, the following simplifying assumptions were made by the New South Wales EPA:
1 $OU_{\text{V EPA Method B2}} = 0.5 \times ou_E/m^3$ (Bardsley and Demetriou 1999)
1 $OU_{\text{QDEH Method 6}} = 3.5 \times ou_E/m^3$ (Verral 1997)
1 $OU_{\text{NSW EPA/SWB Method}} = 3 \times ou_E/m^3$ (NSW EPA and SWB 1994)

It must be noted that these factors are gross simplifications and may be significantly affected by random variability in the methods, that may be large relative to the methodological bias of each method.

Using these factors a degree of comparison can be made of historical and proposed odour exposure criteria in Australia, as presented in Table . From this comparison it becomes clear that considerable differences exist between the criteria as proposed in the different states of Australia.

Organisation	Criteria	(OU/m³)	Olfactometry	Corrected ou_E/m^3	Averaging	time	Percentile	Source type
NSW	draft	2.0–7.0	DAS	2 to 7	0.1 to 1	second	99.0	All
NSW	(old)	1	EPA/SWB	0.3	3	minute	99.0	Scheduled
NSW	(old)	2	EPA/SWB	0.7	3	minute	99.5	Non-scheduled
Queensland	(draft)	10	DAS	10.0	1	hour	99.5	All
Queensland	(old)	2.5	M6	0.7	3	minute	99.5	Area
Queensland	(old)	0.5	M6	0.1	3	minute	99.5	Wake-affected stack
Victoria	(new)	1	DAS	1	3	minute	99.9	All
Victoria/SA	(old)	1	B2	2	3	minute	99.9	All
Victoria		5	B2	10	3	minute	99.5	Broiler chickens
RIRDC		5	DAS	5	1	hour	99.5	Broiler chickens
Western Australia	draft	2	DAS	2	1	hour	99.9	all

Table 14 Comparison of historical and proposed odour impact criteria in Australian states, with tentative correction for differences in measurement method to $ou_E \cdot m^{-3}$ units.

A.7.1. Australia – Western Australia

The Environmental Protection Authority of Western Australia has issued draft guidance on odours in April 2000:

- Environmental Protection Agency, *Guidance for the assessment of environmental factors (in accordance with the Environmental Protection Act 1986). Assessment of Odour Impacts*, No 47, Draft, April 2000

The guidance is based on the environmental Protection Act of 1986, which states:

- *Section 49(1) In this section* ***unreasonable emission*** *means an emission of noise, odour or electromagnetic radiation which* ***unreasonably interferes*** *with the health, welfare, convenience, comfort or amenity of any person*
- *Section 49(5) A person who: a. emits and unreasonable emission from any premises orb. causes and unreasonable emission to be emitted from any premises commits an offence*

The Guidance assumes that best practicable engineering design and best practice management will be applied with a view to minimise odour impacts. For odour impact assessment it takes an approach based on olfactometry to determine emissions at source, combined with dispersion modelling. Air quality criteria are formulated on that basis. The criteria are differentiated for different odorants or odorant mixtures on the basis of the relation between perceived intensity and odour concentration.

An odour assessment comprises three main steps:

- Odour source quantification and intensity analysis through dynamic olfactometry;
- Dispersion modelling of the odour emissions; and
- Comparison to appropriate criteria.

For olfactometry, the standard refers to the Dutch NVN2820 standard, the CEN draft EN13725 and the draft Australian standard DR 99306 *Air quality - Determination of odour concentration by dynamic olfactometry*. For intensity analysis the German standard method VDI3882.

Dispersion modelling is to be carried out using the AUSPLUME model.

The general odour impact criterion is:

- Odour impacts will not exceed 2 odour units (based on the NVN2820 standard) with one hour averaging and 99.9 percentile compliance.

It is not clear whether the authors of the guidance are aware that 2 ou/m^3 according to NVN2820 is actually equivalent to 1 $ou_E \cdot m^{-3}$.

The applicant can also choose to propose an alternative criterion, where an 'equivalent odour concentration' is determined to replace the default odour impact criterion of $C_{99.9,\ 1\text{-hour}} < 1\ ou_E \cdot m^{-3}$. To arrive at such a criterion, the intensity curve needs to be determined according to the VDI3882 method. The odour concentration that is equivalent with the 'distinct odour' intensity scale step will be used to replace the default $C_{99.9,\ 1\text{-hour}}$ concentration.

An example is provided for poultry rearing odours, that are 'distinct' on the intensity scale at a concentration of 7 ou/m^3. This would result in an odour guideline criterion for air quality of $C_{99.9,\ 1\text{-hour}} < 7$ ou/m^3.

A.7.2. Australia – New South Wales

The Environmental Protection Agency of New South Wales issued a draft policy on odours in January 2000:

- NSW EPA, *Assessment and Management of Odour from Stationary Sources In NSW*, Draft, Sydney, January 2001.

This policy is accompanied by a separate booklet:

- NSW EPA, *Technical Notes: Assessment and Management of Odour from Stationary Sources in NS*W, Draft, Sydney, January 2001.

The documents are available on the website of the NSW-EPA: www.epa.nsw.gov.au .
The legal basis for the policy is the *Protection of the Environment Operations Act 1997* (POEO Act) and the *Environmental Planning and Assessment Act 1979 (as amended).*

The POEO Act defines 'air impurities' and 'air pollution' as follows:

> **air impurity** *includes smoke, dust (including fly ash), cinders, solid particles of any kind, gases, fumes, mists, odours and radioactive substances.*
> **air pollution** *means the emission into the air of any air impurity.*

Section 129 of the POEO Act prohibits the emission of an 'offensive odour' from scheduled premises. However, it also provides [in 129(2)(a)] for negotiation of acceptable odour limits through the licensing process. The provision is as follows:

> ***129. Emission of odours from premises licensed for scheduled activities***
> *(1) The occupier of any premises at which scheduled activities are carried on under the authority conferred by a licence must not cause or permit the emission of any offensive odour from the premises to which the licence applies.*
> *(2) It is a defense in proceedings against a person for an offence against this section if the person establishes that:*
> *(a) the emission is identified in the relevant environment protection license as a*

> *potentially offensive odour and the odour was emitted in accordance with the conditions of the licence directed at minimising the odour, or*
> *(b) the only persons affected by the odour were persons engaged in the management or operation of the premises.*
> *(3) A person who contravenes this section is guilty of an offence.*

The draft policy is meant to provide an operational meaning to the concept of 'offensive odour'. The stated aim of the policy is:

> *'...to provide an effective future planning and regulatory regime for potential odour-generating activities. The goal is to introduce a system that will protect the environment and at the same time promote fair and equitable outcomes for odour generators and people affected by odour emissions.'*

The policy states a general set of odour impact criteria:

> ***1 Ground level concentration (glc) criteria for individual odorous pollutants****. The policy adopts the Victoria EPA ground level concentration criteria. These criteria are based on odour threshold or toxicity threshold (whichever is more stringent) and should not be exceeded at any location beyond the boundary of a facility.*
>
> ***2 Odour performance criteria for complex mixtures of odours****. The policy introduces a range of odour criteria which depend upon the surrounding population density. These criteria should not be exceeded at the nearest sensitive receptor (both existing and any likely future sensitive receptors). If a receptor is, or is likely to be, located near the boundary of a facility, then the criteria should be applied at and beyond the boundary of the premises. A level of 7 odour units (OU/m^3) is deemed to be the appropriate exposure level for a single affected residence. For a larger population, in which there will be a greater range of sensitivities to odour (and a higher number of more sensitive individuals), acceptable odour is defined to be 2 OU/m^3*
>
> *Depending on the specific nature of the odour involved, these criteria may be applicable to point sources or diffuse sources or a combination of both.*
>
> *In no situation will the* ***glc or odour performance criteria be used as environment protection licence conditions*** *. Compliance with these criteria is difficult to measure so they are meaningless as licence conditions. For point sources, a specific stack emission concentration limit may be calculated so that the glc or odour performance criteria can be met. Such stack emission concentration limits may be used as licence conditions where appropriate.*

The policy motivates the exposure criteria as follows:

> *Experience gained through odour assessments for proposed and existing facilities in NSW indicates that an odour performance criterion of 7 OU/m^3 is likely to represent the level below which 'offensive' odours should not occur (for an individual with a 'standard sensitivity' (to odours). Therefore, the policy recommends that, as a design criteria, no individual be exposed to ambient odour levels of greater than 7 OU/m^3 Appropriate averaging periods are discussed in Technical Note 3.*
>
> *Odour performance criteria need to be designed to take into account the range in sensitivities to odours within the community, and provide additional protection for individuals with a heightened response to odours, using a statistical approach which depends upon the size of the affected population. As the affected population size increases, the number of sensitive individuals is also likely to increase, which suggests that more stringent criteria are necessary in these situations. In addition, the potential for*

cumulative odour impacts in relatively sparsely populated areas can be more easily defined and assessed than in highly populated urban areas. It is often not possible or practical to determine and assess the cumulative odour impacts of all odour sources that may impact on a receptor in an urban environment. Therefore, the proposed odour performance criteria allow for population density, cumulative impacts, anticipated odour levels during adverse meteorological conditions and community expectations of amenity. Where a number of the factors above simultaneously contribute to making an odour 'offensive', an odour criteria of 2 OU/m^3 *at the nearest sensitive receptor (existing or any likely future receptor) is appropriate, which generally occurs for affected populations equal to or above 2000 people. A summary of odour performance criteria for various population densities is shown in the table below.*

Population of affected community	Odour performance criteria (odour units/m^3)
Urban area ((>2000)	$C_{99.9,\ 3\ \mathrm{minute}} \leq 2.0$
500 to 2000	$C_{99.9,\ 3\ \mathrm{minute}} \leq 3.0$
125 to 500	$C_{99.9,\ 3\ \mathrm{minute}} \leq 4.0$
30 to 125	$C_{99.9,\ 3\ \mathrm{minute}} \leq 5.0$
10 to 30	$C_{99.9,\ 3\ \mathrm{minute}} \leq 6.0$
Single residence (□□2)	$C_{99.9,\ 3\ \mathrm{minute}} \leq 7.0$

Table 15 Odour performance criteria in odour units as proposed by the EPA of New South Wales, Australia, January 2001.

The policy identifies three levels of impact assessment:

*- **Level 1** is a 'rule of thumb' assessment based on generic parameters for the type of proposed facility and site. It requires minimal data and uses simple equations to conservatively predict the extent of any odour impact.*

*- **Level 2** is a 'screening' level dispersion modelling technique, using worst case input data (rather than site-specific data). It is more rigorous, less conservative and more realistic than a Level 1 assessment.*

*- **Level 3** is a 'refined' level dispersion modelling technique using site-specific input data. This is the most comprehensive and most realistic level of assessment available.*

The proponent of a proposed facility should choose the level of assessment (to be presented in a development application or environmental impact statement) depending on the specific characteristics of the proposal and the likelihood of operational odour impacts.

The policy sets out a very ambitious target in terms of dispersion modeling, based on the 99.9 or 100th percentile of 3-minute average concentrations. These are to be calculated using a sophisticated peak to mean ratio mechanism that was developed specifically for this policy, which is described in more detail in section 0 of this report

The relationship between the levels of assessment and the criteria to be applied is outlined below:

*To quantitatively determine the frequency, intensity and duration of odours, the ground-level concentration criteria should be reported as the **100**th percentile of dispersion model predictions for Level 2 odour impact assessments and the **99.9**th percentile for Level 3 odour impact assessments. For point source discharges, stack-emission concentration limits can be included on the environment protection licence. This will help to ensure compliance with the ground-level concentration criteria.*

For dispersion modelling purposes, the glc criteria should be applied at any location at or beyond the site boundary as follows:
1 Impacts for glc pollutants must be reported for an averaging period of ***3 minute****s.*
2 For Level 2 odour impact assessments, impacts must be reported as the ***100****th percentile of dispersion model predictions.*
3 For Level 3 odour impact assessments, impacts must be reported as the ***99.9****th percentile of dispersion model predictions.*
4 Compliance with the glc criteria is to be determined by using source emission measurements and dispersion modelling only.
5 For point sources, dispersion modelling results will be used as the basis for developing licence limit concentrations on stack discharges for glc pollutants.
6 It is not appropriate to use the glc criteria as default license conditions for a facility.

The policy offers the option to develop specific odour exposure criteria through the process as shown in the figure below:

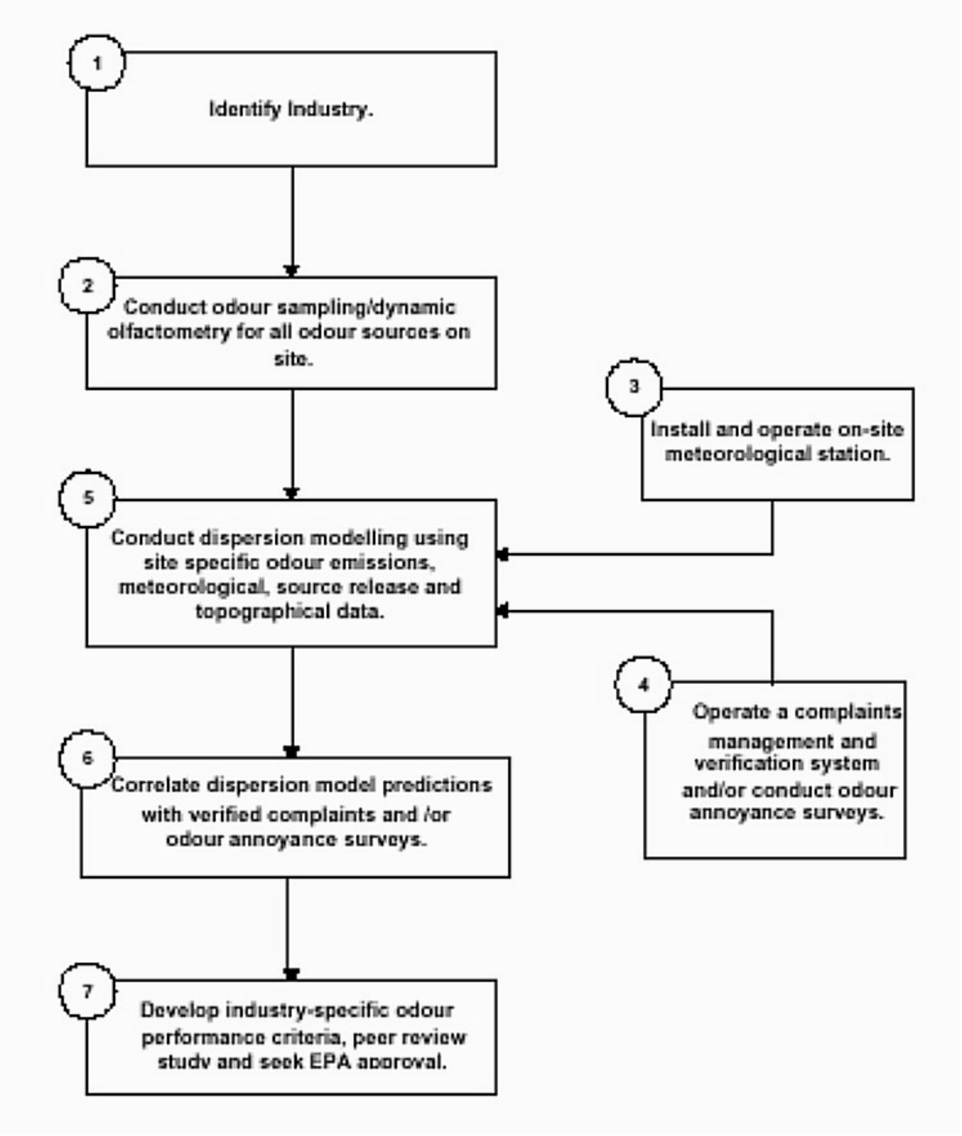

Figure 28 Process for developing specific odour performance criterion in NSW, Australia

A.7.3. Australia - Victoria

Since the Victoria EPA was formed in 1970 it has developed an approach for reducing and managing odours. Odours and aesthetics are specifically included in the *Environment Protection Act* of 1970, which in section 41 prohibits *'making the atmosphere offensive to the senses of human beings'*. EPA licences for premises scheduled under the *Environment Protection (Scheduled Premises and Exemptions) Regulations* of 1996 include the standard condition that '*odours offensive to the senses of human beings must not be discharged beyond the boundaries of the premises'*.

Odour prevention and control has been formalised in State Environment Protection Policies (SEPP's) of which two relate to air issues:

- SEPP AAQ : Ambient Air Quality
- SEPP AQM : Air Quality Management

The essence of the approach is :

- The exposure to a long list of substances is to be limited by setting limits for ground level concentrations (GLC's). A number of these glc's are set on the grounds of odour, while others are defined on the basis of toxicological data.
- For odours that are not included in the GLC substance list, a limit concentration of 1 OU is set
- For assessment of GLC's dispersion modelling may be used, with a prescribed Gaussian model, calculating a 99.9-percentile for 3-minute average concentrations
- A prescribed Victoria method of olfactometry is to be used, called the EPA B2 method. Victoria is the only Australian state that intends to maintain its own standard protocol for olfactometry, instead of adopting the impending Standards Australia method.

The policy is currently being revised. The main change is that the list of GLC concentrations would be replaced by values indicated in a document of the US-EPA:

- US-EPA, (1992) *Reference Guide to Odor Thresholds for Hazardous Air Pollutants Listed in the Clean Air Act Amendments of 1990*, US Environmental Protection Agency, (EPA600/R-92/047).

The list of existing design GLC's and the *design criteria* concentrations that are now proposed for substances that are mainly regarded as odorants is presented in Table .
An overview of the current policy objectives and the proposed changes in the drafts is provided in the background paper produced by the Victoria EPA, printed below:

> *APPROACHES TO ODOUR MANAGEMENT*
>
> *INTRODUCTION*
>
> *Offensive odours from industry are a worldwide problem that has existed for many years. Since its inception in 1970, EPA Victoria (EPA) has developed a consistent approach for reducing and managing odours in the local environment. Significant improvements have been made since that time, however odour continues to be a problem and about 40% of all the pollution complaints currently received by EPA are about odour. Odours and aesthetics are specifically included in the definition of 'environment' in section 4 of the Environment Protection Act 1970 (the 'Act'). Pollution of the atmosphere is an offence under the Act and, as defined in section 41, prohibits the act of making the atmosphere 'offensive to the senses of human beings'.*

The Beneficial Uses specified in the SEPP (AQM) include the protection of local amenity and aesthetic enjoyment. EPA has developed a range of statutory and non-statutory procedures for preventing and resolving odour problems, including works approval and licensing, pollution abatement notices, and the development of environment improvement plans. EPA licences for premises scheduled under the Environment Protection (Scheduled Premises and Exemptions) Regulations 1996 include the standard condition that 'odours offensive to the senses of human beings must not be discharged beyond the boundaries of the premises'. Odour prevention and control strategies have been formalised in State environment protection policies (SEPPs). Currently there are two SEPPs relating to air issues, State Environment Protection Policy (Ambient Air Quality) [SEPP (AAQ)] and State Environment Protection Policy (Air Quality Management) [SEPP (AQM)]. EPA is currently varying the SEPP (AQM). SEPP (AQM) refers to odours in two ways:

1. *Odours from emissions of one or more known chemicals; each substance having its own odour strength and characteristics.*
2. *Odours from emissions of a mixture of unidentified substances, for example, odours from piggeries and broiler farms.*

For known compounds, the odour strength of the emissions can be reliably estimated by measuring the concentration of the chemical. For mixtures of unknown substances, odour strengths are estimated by a panel of trained human noses using the EPA's standard analytical procedure, No. B2 Odour Dynamic Olfactometry, known as the B2 method. Odour strengths are calibrated based on the principle that 1 odour unit (OU) is the level of odour which can just be detected by the average human nose.

CURRENT POLICY OBJECTIVES

Clause 42 of the existing SEPP (AQM), requires the control of odorous substances that 'create or are likely to create objectionable conditions for the public'. Odour management requirements in the existing SEPP (AQM) include: □□at least good control practice for all emission sources;

- *additional technological, operational and management requirements for particular industries or activities listed in Schedule F to the policy;*
- *appropriate land use planning to include buffer distances to limit the impact of odours. The EPA document, Recommended Buffer Distances for Industrial Residual Air Emission (EPA Publication AQ 2/86 July 1990), provides the currently recognised recommendations in Victoria.*
- *design ground level concentrations for odorous pollutants, where the odour thresholds are more stringent than the health-based criterion for the same substance.*
- *a design ground level concentration for all other odorous wastes of 1 OU;*
- *plume calculation procedures for modelling emissions using a 3 minute average, to ensure that proposed emissions will meet the appropriate design ground level concentration; and*
- *odour measurement using the EPA's standard B2 method.*

DRAFT POLICY OBJECTIVES

The overall approach to emissions management in the draft SEPP (AQM) is based on the principles of eco-efficiency and the waste hierarchy. In particular, the management of emissions will focus primarily on emissions avoidance and minimisation through the application of cleaner production principles. Residual *emissions will then be appropriately controlled and dispersed to protect the beneficial uses of the environment. Issues specifically related to odour management incorporated in the draft SEPP (AQM) and detailed in the relevant guidelines for environmental management (GEMs) include:*

- *the selection and use of design criteria for odour;*
- *methods for odour modelling and odour measurement;*
- *the role of separation distances (buffer distances) and land use planning; and additional control requirements for particular groups of industries.*

The odour-based dglcs in the existing SEPP (AQM) were derived from a review of the published odour thresholds available at the time of the development of the SEPP (The Air Environment) with a safety factor applied. The general approach was to adopt the lowest published value to provide protection for the most sensitive members of the population. These dglcs were used in the same manner as the toxicity-based dglcs – as a modelling tool used with the regulatory model in the assessment of the design of industrial premises. In the review of the SEPP (AQM) it was considered that the odour-based design criteria must be updated to reflect the currently accepted odour thresholds for the pollutants covered by the policy. The draft SEPP (AQM) proposes to adopt the US EPA odour thresholds for single chemical odours. EPA decided that the odour thresholds published by the US EPA provided the most appropriate list of published odour thresholds for the purposes of the policy. This approach is also consistent with the approach taken by other jurisdictions in Australia. This is discussed further in the background paper, Indicators for Air Quality Management and Criteria for Assessment. General odours will be formally defined in the GEM for Indicators for Air Quality Management, as (unclassified) air quality indicators of local amenity and aesthetic enjoyment of the air environment. For these indicators, a design criterion of 1 OU at the boundary of the premises will be retained for design purposes to protect amenity in all areas. Prior to EPA issuing a works approval for new sources of emissions, estimates of the resulting maximum ground level concentrations (99.9 percentile value) of pollutants need to be calculated to ensure compliance with design criteria. The draft SEPP (AQM) requires that the EPA-approved dispersion model be used for these calculations. Key features of the application of dispersion modelling procedures to odorous substances are:

- *modelling is performed to predict maximum (99.9 percentile), 'worst case', ground level concentrations of indicators, using a full year of relevant meteorological data;*
- *for odorous emissions, 3 minute average figures at ground level are calculated for comparison with design criteria; and*
- *the predicted ground level maxima in the local air environment must be less than the design criteria. Detailed information on the use of the approved model will be available in the GEM for Dispersion Modelling.*

A background paper on modelling issues has been released for consultation.

Measurement

Odours arising from known chemicals with design criteria can be individually measured using standard laboratory techniques. The EPA B2 method for odour measurement is used for odours comprising a mixture of one or more substances that have not been individually identified. The current method has been used satisfactorily by EPA for a number of years to assist in the resolution of odour problems. An *enhanced B2 method is currently being developed to ensure the best possible results are obtained.*

SEPARATION DISTANCES
Proper land use planning is one of the most important tools in odour management. Many odour problems can be avoided by the appropriate siting of new facilities. Separation distances are provided as a risk management tool to manage unexpected or accidental emissions from an industry. Separation distances provide an additional level of protection by allowing more distance and space in which emissions may dissipate without adversely affecting sensitive land uses. Separation distances are not a substitute for good odour management as described in section 3.1. They are provided to cater for non-routine emissions that may arise from upsets in normal operations of a premise. The draft SEPP (AQM) will include a GEM for recommended separation distances between emission sources and sensitive land uses. Planning and other responsible authorities will be required to apply the guidelines in assessing the suitability of proposed development locations and the potential impacts of development. Separation distances will not be offered or used as a substitute for the effective management of emissions at source.

RESOLUTION OF ODOUR PROBLEMS *Complaints about odour remain the primary indicator of the acceptability of odours in particular situations and a key driver of improvement programs for particular premises that are causing odour problems. As a general rule EPA will seek to negotiate agreement on the measures necessary to resolve odour problems in consultation with the affected community and the management of the responsible premises. Should remedies not be developed and implemented to EPA's satisfaction, then EPA will employ statutory tools requiring action to be taken to reduce odour emissions. Any enforcement action taken will be in accordance with EPA's enforcement policy.*

Copies of the draft policies, draft PIA and accompanying background papers can be downloaded from EPA's website ***www.epa.vic.gov.au***

Victoria EPA design criteria concentrations for odorous substances, existing (1981) and proposed (2001)

Pollutant	Odour	Odour	toxicity (1 hour)		
	ppm	mg/m3	ppm	mg/m	(at 25^{o}C 101.325 kPa
1,3-Butadiene	0.45	1			VICEPA1981
Acetaldehyde	0.042	0.076			VICEPA1981
Acetaldehyde	0.067		3.33		VICEPA2001 (proposed)
Acetic acid	0.2	0.5			VICEPA1981
Acetic acid	0.48		0.33		VICEPA2001 (proposed)
Acetone	20	48			VICEPA1981
Acetone	13		16.7		VICEPA2001 (proposed)
Acrylic acid	0.094				VICEPA1981
Acrylic acid	0.092		0.067		VICEPA2001 (proposed)
Benzyl chloride	0.0094	0.047			VICEPA1981
Butyl mercaptan	0.004	0.012			VICEPA1981
Butyl mercaptan	0.001		0.017		VICEPA2001 (proposed)
Carbon disulphide	0.042	0.13			VICEPA1981
Carbon disulphide	0.11		0.33		VICEPA2001 (proposed)
Chlorobenzene	0.042	0.2			VICEPA1981
Chlorobenzene	1.3		0.33		VICEPA2001 (proposed)
Cumene	0.008	0.039			VICEPA1981
Cumene	0.032		1.67		VICEPA2001 (proposed)
Cyclohexanone	0.12	0.48			VICEPA1981
Cyclohexanone	0.88		0.83		VICEPA2001 (proposed)
Diacetone alcohol	0.28	1.3			VICEPA1981
Diacetone alcohol	0.28		1.67		VICEPA2001 (proposed)
Diethylamine	0.02	0.06			VICEPA1981
Diethylamine	0.13		0.33		VICEPA2001 (proposed)
Dimethylamine	0.0094	0.017			VICEPA1981
Dimethylamine	0.34		0.33		VICEPA2001 (proposed)
Diphenyl ether	0.02	0.14			VICEPA1981
Diphenyl ether	0.0012		0.033		VICEPA2001 (proposed)
Ethanol	2	3.8			VICEPA1981
Ethanol	84		33.3		VICEPA2001 (proposed)
Ethyl acetate	6.3	22.1			VICEPA1981
Ethyl acetate	3.9		6.67		VICEPA2001 (proposed)
Ethyl acrylate	0.0002	0.0008			VICEPA1981
Ethyl acrylate	0.0002		0.17		VICEPA2001 (proposed)
Hydrogen sulphide	0.0001	0.00014			VICEPA1981
Hydrogen sulphide	0.0001		0.33		VICEPA2001 (proposed)
Methanol	4.26	5.5			VICEPA1981
Methanol	100		6.67		VICEPA2001 (proposed)
Methyl ethyl ketone	2	5.9			VICEPA1981
Methyl ethyl ketone	17		5		VICEPA2001 (proposed)
Methyl isobutyl ketone	0.1	0.41			VICEPA1981
Methyl isobutyl ketone	0.88		1.67		VICEPA2001 (proposed)

Methyl mercaptan	0.00042	0.00084		VICEPA1981
Methyl mercaptan	0.0016		0.017	VICEPA2001 (proposed)
Methyl methacrylate	0.05	0.21		VICEPA1981
Methyl methacrylate	0.049		3.33	VICEPA2001 (proposed)
Methyl styrene	0.29		1.67	VICEPA2001 (proposed)
Methylamine	0.0042	0.005		VICEPA1981
Methylamine	3.2		0.33	VICEPA2001 (proposed)
n-Butanol	0.3	0.9		VICEPA1981
n-Butanol	0.83		1.67	VICEPA2001 (proposed)
Nitrobenzene	0.00094	0.0047		VICEPA1981
Nitrobenzene	1.9		0.033	VICEPA2001 (proposed)
n-Propanol	0.03	0.075		VICEPA1981
n-Propanol	2.6		6.66	VICEPA2001 (proposed)
Perchloroethylene	0.94	6.3		VICEPA1981
Perchloroethylene	47		1.67	VICEPA2001 (proposed)
Phenol	0.0094	0.036		VICEPA1981
Phenol	0.06		0.033	VICEPA2001 (proposed)
Phosphine	0.0042	0.0056		VICEPA1981
Phosphine	1		0.01	VICEPA2001 (proposed)
Pyridine	0.0042	0.013		VICEPA1981
Pyridine	0.17		0.17	VICEPA2001 (proposed)
Styrene (monomer)	0.05	0.21		VICEPA1981
Styrene (monomer)	0.15		1.67	VICEPA2001 (proposed)
Toluene	0.17	0.65		VICEPA1981
Toluene	2.8		3.33	VICEPA2001 (proposed)
Triethylamine	0.09	0.36		VICEPA1981
Triethylamine	0.48		0.1	VICEPA2001 (proposed)
Xylene	0.08	0.35		VICEPA1981
Xylene	0.73		2.67	VICEPA2001 (proposed)

Table 16 Victoria EPA design criteria concentrations for odour and toxicity, for primarily odorous substances: existing and proposed values.

A.7.4. Australia – Queensland

The main focus in Queensland for odours is on cattle feedlots and other sectors of primary production.

A schedule of setback distances has been developed for cattle feedlots, in a document titled: *The Queensland Government Guidelines for Establishment and Operation of Cattle Feedlots, 1989.* It uses a formula with a number of inputs: number of cattle, stocking density, density of population in the vicinity, terrain factor and vegetation factor.

Recently an air quality criterion of $C_{98,\ 1\text{-hour}} \leq 10$ ou·m^{-3} was used as a condition in a licence for a new piggery in Queensland.

A.8. Canada

In Canada the responsibility for odour regulations lies with the provinces. Various provinces have their own odour regulation or policy, typically aimed at agricultural sources.

Ontario has a regulation since 1976 titled *Agricultural Code of Practice* that applies setback distances to livestock facilities. As an example:

- for 1000 fattening pigs a setback distance would apply of 405 m to a home and 810 m to a home not belonging to the farm or an urban area.
- for 52 000 chickens a setback distance would apply of 234 m to a home and 468 m to a home not belonging to the farm or an urban area.

Manitoba also uses a schedule of setback distances for livestock units

Size of operation (animal units)	Setback to Home	Setback to Built up area
400 to 800	250	1330
800 to 1600	300	1600

In Alberta an ambient air quality guideline for Hydrogen Sulphide of 10 ppb/v as a one hour average is applied for the specific purpose of odour impact management. This would amount to 20 $ou_E \cdot m^{-3}$ on the basis of the smell of H_2S only, with an odour threshold of 0.5 ppb/v. In addition an Ammonia criterion of 2 ppm/v applies. On 10 days in 1998 and 1999 the Alberta Environment agency conducted downwind surveys of 14 livestock feeding facilities. They found that the air quality criterion for Hydrogen Sulphide was exceeded at two of these sites at 30 m from the source. For Ammonia all measurements were within the guideline criterion.

A.9. United States

In the United States, there is no odour policy at the federal level. The Environmental Protection Agency has engaged in odour related research until the early 1980's which was then halted. The EPA has published a compilation of odour thresholds in 1992:

- US-EPA, (1992) *Reference Guide to Odor Thresholds for Hazardous Air Pollutants Listed in the Clean Air Act Amendments of 1990*, US Environmental Protection Agency Air Risk Information Support Center, (EPA600/R-92/047).

The method of odour measurement is not well standardised. A standard exists, generally called the ASTM Syringe method:

- ASTM D1391-57 (1972): *Standard Method for Measurement of Odor in Atmospheres*, Annual Book of ASTM Methods Part 23, Amer. Soc. Test. Mater., Philadelphia, Pa

The ASTM syringe method for olfactometry is generally viewed as ineffective, and no new standard is being developed. Many odour thresholds in US publications indicate unrealistically high concentrations of the compound involved. The main cause is the practice of using very low flows of odorant mix in olfactometers, of 0.1 to 3 liter/minute, which is well below the normal human inhalation rate. A number of universities have now adopted the method as described in EN13725 'Air quality – Determination of odour concentration by dynamic olfactometry'. These universities are typically involved in research of agricultural livestock odours (Duke University, Iowa State University, the University of Minnesota, Purdue University). In addition wastewater treatment organisations use this method (Los Angeles County Sanitation District, Minnesota Metropolitan Council) (Mahin, 2001).

Regulation and management of odour related annoyance is a task that is carried out on the state or county level. There is a wide variety of approaches.

The main odour regulation issues are related to livestock operations and wastewater treatment.
The use of odour unit or dilution to threshold (D/T) limits is relatively common, but the values applied, averaging times, percentiles and methods of assessment vary considerably, as is illustrated in Table .

In the agricultural sector, odour complaints are a topical issue, in the light of considerable centralisation of production in more corporate business structures. The US Department of Agriculture task force on air quality recently issued a report:
USDA, (2000) *Air quality research and technology transfer white paper and recommendations for concentrated animal feeding operations*, Confined Livestock Air Quality Committee of the ASDA Agricultural Air Quality Task Force, July 19, 2000

Entity	Exposure limit	method	Averaging time	percentile	remarks
Allegheny County WWTP	4 D/T		2 minute		Wastewater treatment
(San Francisco) Bay Area Air Quality District	5 D/T				applied after at least 10 complaints in a 90-day period
Colorado	7 D/T	Scentometer			
Connecticut	7 D/T				
Massachusets	5 D/T		1 hour		
North Dakota	2 D/T	Scentometer			
Oakland, California	50 D/T		3 minute		
New Jersey	5 D/T		5 minute		Biosolids handling and treatment
Oregon	1 to 2 D/T		15 minute		
San Diego WWTP	5 D/T		5 minute	99.5	
Seattle	5 D/T		5 minute		

Table 17 Examples of odour exposure criteria used in the USA. (Source: Mahin, 2001)

The American Society of Agricultural Engineering published a code of practice:

- ASAE, *Control of Manure Odours*, Engineering Practice 379.1.

That recommends setback distances to separate livestock units from residents between 800 m for neighbouring residences and 1600 m for residential development.

The State of Minnesota has a feedlot air quality programme, in which the Minnesota Pollution Control Agency is appointed to monitor air quality around feedlots though measurement of Hydrogen Sulphide concentrations in air. The monitoring programme involved 137 feedlots, of which 24 were found to have the potential to exceed the air quality criterion:

- 30 ppb/v H_2S as a 30 minute average not to be exceeded on more than 2 days in a five day period (this would be at least 60 $ou_E \cdot m^{-3}$, based on an odour threshold for H_2S of 0.5 ppb/v, not taking into account other odorants)
- 50 ppb/v H_2S as a 30 minute average not to be exceeded on more than 2 times in a year

The Livestock Odour Task Force was established in Minnesota in 1995, and has recommended a system to rate odour emission potential from livestock operations: the Odour From Feedlots – Setback Estimation Tool (OFFSET). This tool is now being piloted for use in determining planning decisions.

In North Carolina, the Attorney General, the top legal official in the state, reached an agreement on July 25, 2000, with Smithfields Food, the dominant pig producer in the state with 276 company owned farms. The agreement provides for elimination of all open-air anaerobic slurry lagoons and spray fields on these farms (Mahin, 2001). To achieve this a detailed research plan was defined, with the Smithfield Foods company providing significant funding of 15 million dollar. The programme is spearheaded by the College of Agriculture and Life Sciences at North Carolina State University.

(Williams, C.M., (2001) *Technologies to address air quality issues impacting animal agriculture*, In: Proceedings of the 1st IWA International Conference on Odour and VOC's: Measurement, Regulation and Control Techniques, University of New South Wales, Sydney, March 25-28, 2001, ed. J. Jiang, International Water Association, ISBN 0 7 334 1769 8.)
An overview of approaches to managing livestock odours is provided in Table .

State	Year	Setback distances to residences and other requirements
Arkansas	1992	Regulation 5: All owners and operators must complete an odour training program
Colorado	1998	Amendment 14. Permit, installation of covers on all anaerobic lagoons, setback distances, minimisation of odour from swine facilities
Georgia		Allows its state EPA to deny permits to agricultural operators with poor compliance records in *or* out of state
Illinois	1998	Setback distance to residential dwellings of 3200 m for units >7000 animal units
Iowa		Setback distance to residential dwellings of 257 to 756m. Rules are proposed requiring the injection of manure into the soil as an alternative to spreading
Kansas	1994	Setback distance to residential dwellings of 1219 m for units > 1000 animal units
Minnesota		State monitors Hydrogen Sulphide ambient air quality standard (30 – 50 ppb/v as a 30-minute average, exceedence no more than 2 days/5 day period or twice a year, respectively)
Missouri	1996	Setback distance to residential dwellings of 914 m for units > 7000 animal units
Nebraska		Permits counties to develop zoning ordinances
North Carolina	2000	For units >250 pigs or 100 cattle, using lagoons or slurry spray irrigation, implement management practices and submit best management plans
Oklahoma	1997	Setback distance to residential dwellings of 800 to 1200 m. Production units > 5000 animal units need a permit, and residents within 1600 m radius are notified
South Carolina	1996	Lagoon setbacks 61 m from the property boundary line if unit > 3000 pigs
South Dakota		Examples are 800 m from homes and 1600 m from 'populated areas' fro 2500 finishing pigs. Setbacks increase for larger facilities
Wyoming	1997	Setback distance to residential dwellings of 1600 m for units > 1000 animal units

Table 18 Overview of odour related pig production siting regulations in US states. (Source: Mahin, 2001)

ANNEX B
OVERVIEW OF RELEVANT LEGISLATION WITH REGARD TO CONTROL OF ODOUR RELEASES AND ODOUR NUISANCE IN THE UK.

B1 Statute (criminal) law

B.1.1 Environmental Protection Act - Part 1

Part 1 of the Environmental Protection Act covers two discreet regimes of control:

- IPC – Integrated Pollution and Control for the most complex and polluting processes with emissions to air, land and water.
- LAAPC – Local authority pollution control for less polluting small processes covering emissions to air only.

In both cases, the principal vehicle of Part of Act is contained within the Prescribed Processes and Substances Regulations (1991). These regulations specify the industrial processes which are prescribed by the secretary of state and as such require an authorisation to operate.

In both cases, some odorants are classified as "prescribed substances" and will be subject to the requirement to use BATNEEC (Best Available Techniques Not entailing Excessive Cost) "for preventing the release of substances …… or where that is not practicable by such means, for reducing the release of such substances to a minimum and for rendering harmless any such substances which are so released…"

However, for Part B processes, the concept of Best Available Technique Not Entailing Excessive Cost (BATNEEC) is used to control the emissions of odours to air only and does not apply to odorants released from liquid or solid sources.

For other odorants which do not fall within Schedule 4 of The Environmental Protection (Prescribed Processes & Substances) Regulations 1991 (as amended) the requirement is for "rendering harmless any other substances which might cause harm if released into any environmental medium" applies - EPA'90 sec7(2)(a)(ii). This concept applies to Part A processes only and in this context, harm is offence to man's senses or harm to his property. Sec 1(4) EPA'90.

Hence for both Part A and B processes regulated under Part 1 of the protection act, the regulating authorities main control is through the "authorisation" system, and setting of appropriate conditions, to control the activities and define precautions to be taken to be carried out in connection with or in consequence of the processes activities.

B.1.2 IPPC

The Integrated Pollution, Prevention and Control (IPPC) Directive, as implemented by the Pollution Prevention and Control Regulations 1999 stipulates that offensive odour emissions will be prevented or where that is not practicable, reduced in order to achieve a high level of protection of the environment as a whole. This approach is very similar in concept to the IPC system, however IPPC is much wider in both scope and coverage.

Those activities covered by IPPC are listed in Annex 1 to the Directive which has been implemented in domestic legislation by a schedule attached to the Pollution Prevention and Control Regulations. The regulation of those activities will be shared between the Environment Agency and the Local Authorities.

In addition, some activities currently covered by a waste management licence will fall within IPPC. These include:

- Any installation disposing of hazardous waste and some hazardous waste recovery operations.
- Incinerators.
- Disposal of non-hazardous waste by physico-chemical or biological treatment.
- All landfills, other than inert landfills.
- Some sewage treatment works.

The enforcing authority, whether it be the Agency or Local Authorities, in issuing permits, must ensure that the 'Best Available Techniques' (BAT) are used to ensure that all appropriate measures are taken against pollution in particular by the application of BAT and that BAT is used as the basis for setting emission limit values or any other equivalent parameters or technical measures via the permit.

Landfill operations will need to meet the requirements of the Landfill Directive as well as the IPPC Regulations.

B.1.3 Town and Country Planning Act 1990

The Town and Country Planning Act 1990 specifies controls over development under planning law. The planning and pollution control systems, though separate, are complementary in that both are designed to protect the environment from the potential harm caused by development and operations, although with different objectives. The planning system complements the pollution control policies by regulating the location of development and the control of operations in order to avoid or minimise adverse effects on the land use and on the environment, i.e. to ensure serious detriment to the amenities of the locality does not occur.

B.1.4 Statutory Nuisance (section 79 of the Environmental Protection Act 1990, EPA)

The principal route to control odours arising from processes which cannot be regulated under IPC or LAAPC or waste management, is through Part III of the Environment Protection Act 1990. Section 79 of the Environmental Protection Act 1990 states that:
"A Statutory nuisance includes any dust, steam, smell or effluvia arising on industrial, trade or business premises which are prejudicial to health or a nuisance"

Under s79(1)(d) of the EPA, 'any dust, steam, smell or other effluvia arising on industrial, trade or business premises and being prejudicial to health or a nuisance' is a statutory nuisance for the purposes of Part III of the EPA.

Note that, unlike other provisions under this section, s79(1)(d) only applies to smells arising from 'industrial, trade, or business premises' - a smell cannot be a statutory nuisance if it is arising from a private home or a recreational activity. Similarly, a smell arising from contaminated land (s79(1A)) or military land (s79(2)) cannot be an s79 statutory nuisance.
Under s79 of the EPA a statutory nuisance is therefore either prejudicial to health OR a nuisance.

In this context, ‘Prejudicial to health’ is defined as meaning injurious, or likely to cause injury, to health. When determining if something is a nuisance, the relevant case law seems to follows the common law definition of nuisance (refer to section B2 below).

It is the duty of the Local Authority to take steps against an operation or process causing a statutory nuisance. To prevent Statutory nuisance, the Local Authority must serve an abatement notice outlining the steps to be taken to prevent the statutory nuisance. The Local Authority must have regard to the Best Practicable Means (BPM). BPM is interpreted by reference to a number of provisions, which include:

a. ‘practicable’ means reasonably practicable having regard among other things to local conditions and circumstances, to the current state of technical knowledge and to the financial implications;
b. the means to be employed include the design, installation, maintenance and manner and periods of operation of plant and machinery, and the design, construction and maintenance of buildings and structures.

Statutory nuisance does not apply where proceedings to deal with the nuisance could be taken under Part I of EPA'90.

B.2 Common Law - Nuisance

The law of nuisance is concerned with the unlawful interference with a person’s use or enjoyment of land, or of some right over or in connection with it. In attempting to assess liability in a nuisance action, a balance is made between the reasonableness of the defendant’s activity and its impact upon the plaintiff’s proprietary rights.

In assessing the balance the courts will take into account a number of specific factors including the locality of the nuisance, the duration of the nuisance and any hypersensitivity on behalf of the plaintiff.

One of the balancing factors to be taken into account is the amount a nuisance can be ‘sensed’. The law does not take into account ‘trivial unpleasantness’. Nuisance is not actionable without proof of damage. The inconvenience has to be able to be ‘sensed’ by reasonable members of the public. It has to be capable of being smelt by people other than the defendant. Where one person senses a smell, that does not automatically mean an action can be founded. If a potential plaintiff (a ‘hypersensitive’ plaintiff) is particularly sensitive to one type of nuisance then it will not be actionable unless that nuisance would have affected a ‘reasonable’ person.

It is also necessary to take in to account the circumstances and character of the locality in which the complainant is living and any similar annoyances that exists or previously existed there.

A public nuisance is a nuisance that affects a wide class of the public in general. It is a criminal offence to cause a public nuisance. To prove public nuisance there is a need to show an effect over a wide class of the public.

B.2.1 Odour as common law nuisance – case law

There is little case law on odour as common law nuisance. The following cases provide an overview of how this issues has been dealt with from a legislative perspective:
Halsey v Esso Petroleum [1961] 2 All ER 145.

The plaintiff alleged nuisance from smell from adjoining defendant oil depot. The Court found that there was nuisance caused by this smell notwithstanding that there was no proof of injury to the plaintiff's health, as injury to health was not a necessary ingredient in the cause of action for nuisance by smell.

Veale J stated "nuisance by smell or noise is something to which no absolute standard can be applied. It is always a question of degree whether the interference with comfort or convenience is sufficiently serious to constitute a nuisance. The character of the neighbourhood is very relevant and all the relevant circumstances have to be taken into account. What might be a nuisance in one area is by no means necessarily so in another." (at 150)

The judge applied a standard in respect of discomfort and inconvenience from smell as being that of 'the ordinary reasonable and responsible person who lives in this particular area'. The judge went on to say this standard is not necessarily the same one that a plaintiff might set for himself or herself.

The judge concluded that "I am quite satisfied that there is on occasion a smell escaping from the depot, which is far more than what would affect a sensitive person. There is something which is a nauseating smell and this is so frequent as to be an actionable nuisance." (at 153). On balance of the consideration of the character of the neighbourhood and the nature, intensity and frequency of the smell, the court concluded the smell did amount to a nuisance.
Bone and another v Seale [1975] 1 All ER 787

The court found that the smell, from the defendant's neighbouring piggery, was a nuisance:
"There was a considerable weight of evidence, making every allowance for hypersensitivity and making every allowance for exaggeration, that these two sources, boiling swill and the accumulation of pig manure, were so offensive as to constitute an intolerable nuisance over the years. It was an intermittent nuisance; it was a nuisance, which no doubt those who had to live with it tended to exaggerate. But it was a nuisance; it was a serious nuisance, coming and going by day and by night, over a period of something like 12 ½ years."(at 791)

ANNEX C
QUANTIFICATION OF NOISE INDUCED ANNOYANCE AS RELATED TO CURRENT UK LEGISLATION

Nuisance arising from exposure to noise is generally regulated under the nuisance legislation (refer to Annex B).

C.1. Relevant Literature

Absolute values are suggested as limits for purposes of legislation are proposed in number of documents. In addition, set methodologies for measuring noise and interpretation of results are outlined.

C.1.1. British Standard BS 4142:1997.

Those associated with noise legislation will be familiar with this document, which offers advice on the likelihood of receiving complaints of industrial noise affecting mixed residential and industrial areas. The assessment involves calculating the difference between the Background Sound Level (section 0) and the Rating Level (section 0). and the advice is as follows:

- Difference of ≥10dB
  Complaints are likely and the greater the difference the greater the likelihood of complaints
- Difference of ≈5dB
  Marginally significant
- Rating Level >10dB below Background Level
  Insignificant

Olfactometry already assumes that all odour concentrations are above background. However, as the background level is not measured, this is merely a simplification rather than scientific and the measurand.

C.1.2. WHO – Guidelines for Community Noise

This document (Berglund, Lindvall, 1995) proposes that the noise should not be loud enough to give reasonable cause for annoyance to persons in the vicinity.
The guidelines suggest, inter alia, that:

- An outdoor L_{Aeq} greater than 50dB s likely to give moderate cause for annoyance in the daytime or evening
- An external night time level of L_{Aeq} of 45dB or less is required to prevent sleep disturbance.

These are continuous noise levels principally arising from road traffic.
It can be seen that the WHO guidelines simplify the criteria still further and hence are only general guidance, which should be used with caution.

C.1.3. Defining noise levels

The noise levels relevant to legislation are outlined in the documentation listed above. It is critical to note the relationship between the values given for the source in question and noise from other sources. The following definitions are taken from BS 4142:1997.

5. **$L_{Aeq,T}$**

The $L_{Aeq,T}$ is the value of the A-weighted sound pressure level in decibels of continuous steady sound, within the time period T, that has the same mean-squared sound pressure as a sound that varies with time.

6. **Background Sound Level**

   $L_{A90,T}$ is the A-weighted sound pressure level that is exceeded for 90% of the time interval T, measured using the time weighting F, and quited to the nearest whole number of decibels.

7. **Rating Level**

   A noise index – the equivalent continuous A-weighted sound pressure level during a specified time period with the addition of 5dB(A) for tonal or impulsive characteristics of the sound. ($L_{Ar, Tr}$)

It would only be possible to enforce the criteria above for perceived odorants if that which has been identified as causing nuisance was very strong. In addition, it is not possible to separate the main source odour (specific odour if related to terminology above) from the ambient odour in order to achieve the residual odour. The specific odour would be quantified using atmospheric dispersion modelling in practice, and the residual odour would be discounted. This dispersion modelling would in effect give a rating level for odour concentration over time. In olfactometry the reference time interval is the time taken for one sample to be collected.