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Data sheet

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Abstract:	A project within the framework of a larger research programme, Action Plan for the Aquatic Environment III (VMP III) aims towards improving an atmospheric dispersion model (OML). The OML model is used for regulatory applications in Denmark, and it is the candidate model to be used also in future in relation to odour problems due to animal farming. However, the model needs certain improvements and validation in order to be fully suited for that purpose. The report represents a survey of existing literature, models and data sets. It includes a brief overview of the state-of-the-art of atmospheric dispersion models for estimating local concentration levels in general. However, the report focuses on some particular issues, which are relevant for subsequent work on odour due to animal production. An issue of primary concern is the effect that buildings (stables) have on flow and dispersion. The handling of building effects is a complicated problem, and a major part of the report is devoted to the treatment of building effects in dispersion models.
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Summary

This report forms an initial part of a project on improving an atmospheric dispersion model. The dispersion model concerned (OML) is to be used for calculation of odour from animal production.

The OML model is used for regulatory applications in Denmark, and it is the candidate model to be used also in future in relation to odour problems and ammonia deposition due to animal farming. However, the model needs certain improvements and validation in order to be fully suited for these purposes.

The report represents a survey of existing literature, models and data sets. It includes a brief overview of the state-of-the-art of atmospheric dispersion models for estimating local concentration levels in general. However, the report focuses on some particular issues, which are relevant for the subsequent work on model improvements in relation to dispersion of odour from stables.

One issue of primary concern is the effect that buildings (stables) have on flow and dispersion. The handling of building effects is a complicated problem, and a major part of the present report is devoted to the treatment of building effects in dispersion models.

In the subsequent work within the current project, various paths will be followed. As a main path, the potential of integrating OML with PRIME will be explored. PRIME is separate model that specifically addresses building effects; it was developed in the USA during the late 90's.

There are various alternatives to that of using PRIME, and their merits will also be considered during the subsequent work with model development and assessment.

A second issue of concern to odour problems in general is how to deal with the complexities of odour perception and regulation. The report provides an introduction to this topic.

A third issue, which receives considerable attention throughout the report, is the question of obtaining data for model improvement and model assessment. This is necessary for the project, but it is by no means straightforward. Basically, there are three approaches to obtain data for model verification:

a) field measurements;
b) wind tunnel simulation;
c) data obtained by more detailed models than the one being investigated, in particular CFD modelling.

All three approaches have limitations, so it is relevant to consider all of them – possibly in combination – when assessing model performance. The advantages and disadvantages of the three approaches are discussed, and the information is summarised in tabular form in the conclusion (Chapter 7).

Furthermore, the report provides an overview of relevant data sets for model assessment. A substantial number of data sets are mentioned; however, only a small number of these data sets will eventually be selected for actual use within the project.

In general, the present report is a tool to be used for subsequent work on model improvement and model assessment, with focus on the OML model.

1 Background and introduction

Odour caused by animal farming

Atmospheric dispersion models can be used to assess levels of air pollution in the surroundings of sources. A special field of interest is the assessment of odour levels caused by animal farming. This is currently of great concern in Denmark, due to the change of structure in animal production in recent years, in the form of fewer but larger production facilities. Additionally, many people have moved from cities to countryside villages, and this has increased the number of complaints on odour annoyance. Larger production units often result in odour emissions with larger and more distant impacts in the surroundings. The rather high dwelling density in Denmark limits the number of available locations for large animal production facilities. Consequently, there is a great need for reliable atmospheric dispersion models for estimating local concentration levels.

This is the background for a project on improving dispersion modelling as applied to animal farming, being conducted within the framework of a larger research programme, *Action Plan for the Aquatic Environment III* (VMP III) under the Ministry of Food, Agriculture and Fisheries. The current report is an element within the project on dispersion modelling.

The report: An element in preparations for the project

The present report serves to set the scene, in preparation for the remainder of the project. The report summarises information relevant for the subsequent work on model improvement and model assessment.

The OML model

The OML model is used for regulatory applications in Denmark, and it is the candidate model to be used also in the future in relation to handling and regulation of odour problems arising from animal farming. However, the model needs certain improvements in order to be fully suited for this purpose. The anticipated improvements primarily concern the effects that buildings (stables) have on flow and dispersion. There are also other issues of concern, such as the way to deal with the complexities of odour perception and regulation.

Focus of report

The present report provides a brief overview of the state-of-the-art of atmospheric dispersion models for estimating local concentration levels in general. However, the report focuses on some particular issues, which are relevant for the subsequent work.

Such issues include the handling of building effects, the question of reproducing short-term concentration fluctuations, and the question of obtaining data for verification of models, as explained next:

Methods to obtain data for model verification

When assessing a model's performance, the ideal situation would be that one could pose a challenge to a model, obtain a model result, and then compare the model results against a "book of answers".

However, no "book of answers" exists. The closest one can get, is to check model results against "answers" obtained by one of the following methods:

- Field measurements, including both data from intensive experimental campaigns and routine monitoring;
- Data from wind tunnels;
- Data obtained by more detailed models than the one being investigated.

All of these types of data have limitations, and it is therefore relevant to consider all of them - possibly in combination - when assessing model performance. Throughout the report, we will provide an overview dealing with capabilities, advantages and disadvantages of the various data types.

Content of introductory chapter

The special conditions and problems related to odour and animal farming are introduced in the remainder of the current chapter. The discussion includes an overview of distinctive features of odour measurements and odour dispersion, as compared to the behaviour of other pollutants.

Finally, the scope and structure of the entire report is outlined.

1.1 Odour sources in animal farming

Types of sources

The odour emissions in animal farming mainly arise from the animal manure. The emission occurs from different types of sources: stables, manure tanks, transportation and application to fields. Each type of source has a different emission pattern in time and space, depending also on the physical characteristics of the source and the meteorological conditions.

The main source of odour is emission from stables (livestock buildings). Most stables have forced ventilation with emission through well-defined outlets. Some stables are open with natural ventilation, and the emissions are consequently less well defined.

Odour emission from fields is limited in time, and occurs – at least in Denmark - during a few weeks in spring and autumn, but extends over almost the entire agricultural area. Some emission can occur along the roads of transportation because of leakage and waste.

Only well defined point sources are considered in the following.

1.2 Measurements of odour

Odour can be a mixture of many different chemical substances, each having its own odorous characteristics. Thousands of different odours exist. When authorities enforce environmental regulation of odour, the emission of the individual odorous components is normally not known.

In an air sample the contributions of the individual odours substances need not to be additive, but may be enforcing or annihilating each other. Therefore, odour cannot at the moment be measured with conventional types of instruments for chemical components; instead, the human sense of smell must be used.

Olfactometry

Determination of odour concentrations by use of the human sense of smell is called olfactometry. In brief, the method is based on the use of a panel of about 6 persons who in the laboratory are exposed to an odour sample, diluted by varying amounts of clean air. The situation when half of the panel is able to detect an odour while the other half cannot, is defined as the odour threshold; the dilution then has a concentration of one odour unit per cubic meter (OU/m^3). The original concentration can then be determined from the dilution ratio. The European standard EN 13.725 describes the method in detail. The method only works for samples with high concentrations; consequently, it is only used to determine *emission* concentrations. The method has a relatively high uncertainty, which of course can be reduced by repetition (Oxbøl, 2004).

1.3 Human perception of odour and limit values

Odour characteristics: Intensity, character and hedonic tone

The human perception of odour is characterised by intensity (strength), character (e.g. sweet, rotten, etc.) and hedonic tone (acceptability). The most frequently used method to estimate the odour intensity is the category scale method. It is a six point scale: 0 = no odour, 1 = just perceptible, 2 = faint, 3 = easily noticeable, 4 = strong and 5 = very strong.

Odour intensity as a function of odour concentration

The human odour sensation has a non-linear dose-response relationship. It has been demonstrated that the *odour intensity* can be approximated by a logarithmic function of the *odour concentration* (Chen et al., 1999; Winneke et al., 1988). Different odours have different intensity relation to the concentration. In general this means that for odour concentrations less than about 5-10 OU/m^3, small changes of say 2 OU/m^3 can easily be recognised, whereas at levels above 20 OU/m^3 changes must be more than 10 OU/m^3 to be recognised.

When the level of odour annoyance in the neighbourhood of an odour source is assessed, then the frequency and the duration of odour play a major role.

Concentration fluctuations are important for odour impact

A further complication to assessment of odour impacts is that the human response time is a few seconds – or the time of a breath. In the vicinity of an odour source the odour concentrations will fluctuate widely around a mean value, e.g. the hourly mean. Therefore, even in the case when the hourly concentration average is below the odour threshold, there may be short-term levels several times higher than the threshold. The ratio between mean and peak values is not a universal constant, but depends on several parameters (see Section 4.4).

Recovery of sense of smell

Another difficulty in assessment of odour impacts is the human adaptation to odour and the later recovery of the sense of smell. The time to adapt can be a couple of minutes, but the recovery may be faster, and both may depend on the type of odour (Lindvall, 1970, www.environodour.com.au).

Limit value for odour

All of these issues make it difficult to define a proper general limit value for odour in order to avoid annoyance in the neighbourhood of an odour source. Thus, many different types of limit values are in use around the World. The limit values might also reflect the kind of statistics that regulatory dispersion models are capable of calculating. The differences concern the basic averaging period (hour, minute or seconds), the period of assessment (year or month) and the level of percentile (99,9 to 85). An often used limit value is the 98-percentile of hourly mean concentration for one year, but the level of the limit value can vary a lot between countries and for the type of odour or the location (residential or industrial area).

Several countries use limit values based on short-term (minutes) concentrations, but the control of compliance is based on dispersion modelling of hourly mean values that afterwards are corrected to the short-term values by the application of simple methods.

All limit values make use only of the concentration level. But in Germany the authorities have started to take the hedonic tone into account (Both and Koch, 2004). In Denmark the use of short-term odour intensity instead of the concentration has been proposed to the authorities (Løfstrøm, 2000) as basis for a new guideline.

1.4 Scope and structure of the report

Limitations

Compared to the many aspects and complexities of dispersion modelling, this report is limited in scope. The dispersion models in focus are restricted to concern only dispersion - and thus not chemical reactions and deposition. Furthermore, only point sources and the local dispersion (up to a few kilometres) in non-complex terrain are considered.

As previously indicated, the report does not provide a uniform treatment of all modelling aspects, but focuses on particular issues that are relevant for the subsequent work of model improvement and assessment.

The question of obtaining data for verification of models is one of the subjects in focus. Therefore the outline of the report is as follows:

- Chapter 2 introduces and comments on one of the main sources of data for verification of models, namely field measurements - both routine monitoring and intensive experimental campaigns.
- Chapter 3 gives an introduction to wind tunnel data.
- Chapter 4 gives an overview of dispersion models and model components that are of interest in the context of the present project.
- Chapter 5 focuses on methods for modelling building downwash. This is a matter of key importance, because the presence of buildings (stables) has a vital influence on concentration levels in the vicinity of the source. The chapter includes a discussion of

CFD modelling which is yet another source of data for model verification.

- Chapter 6 introduces a number of data sets that can possibly be of use within the current project; only a small number of these data sets will be selected for actual use.

- The Conclusion in Chapter 7 summarises some of the information presented in the previous chapters. In particular, it includes a table listing advantages and disadvantages of various approaches to obtain data for model verification: field measurements, wind tunnels, and CFD modelling.

2 Field measurements

Almost all dispersion models are validated on concentration measurements from full-scale field measurements. Here, the term "field measurements" is meant to comprise both data from routine monitoring and data from intensive experimental campaigns.

Routine monitoring

Routine monitoring of concentrations normally takes place only at few locations – there is not a dense network around a single source. For typical routine monitoring, the pollutants measured cannot be uniquely ascribed to a single source, so the source term may be uncertain.
These facts limit the usefulness of routine data. However, an advantage of routine monitoring is that one can obtain long time series of measurements, covering a broad range of different meteorological conditions.

Intensive campaigns

Intensive campaigns are typically short with duration of a few days or weeks, where experiments are conducted only during a limited number of hours. The spatial resolution of concentration measurements can be high.

Tracers

Intensive experiments are normally performed by measuring tracer concentrations downwind of a source. The source can be an existing single outlet/stack, several outlets on complex buildings or artificially constructed sources.

The tracers can be a 'natural' component released from the source in focus (e.g. NO_x or NH_3). It can also be an added artificial tracer such as inert gases (e.g. SF_6), or smoke, consisting of very small particles. The artificial tracers often have a negligible deposition velocity. In any case, the existing background concentration must also be assessed and accounted for, which can be a major source of uncertainty.

The emission must be known and have a rather constant rate. For 'natural' tracers these facts can be the reason for rather high uncertainties.

Lidar

Artificial smoke is a tracer that can be measured with Lidar (light detection and ranging, e.g. Jørgensen and Mikkelsen, 1993; Jørgensen et al., 1997). The Lidar emits a laser beam and measures the backscatter from the smoke. The signals are processed to give instantaneous concentrations in small volumes of air along the beam. A vertical cross section of the plume can be mapped in a few seconds by scanning the plume, and in this way data with high spatial and temporal resolution can be acquired. The drawback is that the measured concentrations will be in terms of relative values. Anyway, vertical and horizontal standard deviations of the mean plume can be determined and used for validation of the mean dispersion parameters used in Gaussian dispersion models. Additionally, information on short-term concentration fluctuations can be compiled.

The major advantages of full-scale field experiments are:

- They represent reality and real meteorological situations;

- All scales of turbulent eddies are represented, and the large scales are not limited as in wind tunnels;

- All types of meteorology can in principle be studied.

The disadvantages are:

- A certain experimental trial can seldom be repeated under exactly the same meteorological conditions as it can be done in a wind tunnel. This is a matter of concern because of the stochastic nature of atmospheric turbulence (see below).

- The number of meteorological scenarios is limited because the campaign is short (for experimental campaigns).

- An experiment represents only one or a few source configurations (outlet height, building height and building geometry are fixed to one or a few sets of values).

- In a traditional tracer experiment with a limited number of distant monitors it is difficult to determine the maximum concentration and the extent of a plume. For routine measurements it is impossible.

Implications of the stochastic nature of atmospheric turbulence

It is important to be aware that even if it were possible to repeat a field experiment under the same meteorological conditions, then the stochastic nature of the turbulence would result in different concentration levels. This means that a substantial number of trials must be performed in order to minimise the variance, and obtain a true ensemble mean. An ensemble mean is of interest, because this is what regulatory dispersion models attempt to predict. The variation between experiments is a measure of the variability that can be expected in the real world, and thus it provides important information.

3 Wind tunnel data

Advantages and limitations of wind tunnel studies

Wind tunnel studies are an essential tool for development and validation of mathematical dispersion models. The advantage of wind tunnel studies in comparison to field measurements is that some important governing parameters e.g. wind speed, wind direction, source parameters and building configuration can be controlled and changed, and that experiments can be repeated in a well-defined way. Due to the relatively high costs of wind tunnel measurements, they can be performed only for a limited number of sites and parameter combinations. Moreover, only few wind tunnels are equipped so that they can simulate non-neutral stability conditions. The variation in atmospheric stability and the large scale meandering of the wind flow can only be simulated with large efforts. The vast majority of wind tunnel studies are for neutral stratification.

Due to these limitations, the wind tunnel techniques can hardly be used as practical modelling tools. The results are, however, very useful for extending our understanding of processes, and especially as a source of data that can be used for development and testing of mathematical models.

In connection with the current project, wind tunnel studies are interesting regarding the following aspects:

- They can show the *detailed flow field* around simple obstacles (buildings). This will serve the development and validation of the flow calculation in dispersion models that are applied for odour assessment in the near field under building influence.
- They can show the *average concentration field* in different complex configurations.
- They can estimate the characteristics of *concentration fluctuations* in dependence on parameters such as presence of buildings, emission height, distance from the source etc.

A matter of key interest within the current project is the study of building effects. The main part of the existing information about the structure of the wind flow near buildings comes from model experiments in laboratory conditions (physical modelling in wind tunnels, towing tanks etc.). This kind of information is extremely valuable, but special precautions should be taken when transferring the results obtained from laboratory conditions to field conditions - not all aspects of atmospheric flow can be reproduced in the laboratory. The application of wind tunnel techniques to the study of flow and dispersion in building arrays is briefly reviewed by Plate (1999).

CEDVAL

It is worth noting that at the wind tunnel of the Meteorological Institute at the University of Hamburg a validation database is compiled, named CEDVAL (http://www.mi.uni-hamburg.de/cedval/). CEDVAL is a compilation of mainly wind tunnel data sets that can be used for validation of numerical dispersion models. The primary goal of CEDVAL is to provide validation data at a higher level of quality than most of the previously available data.

More in Section 6.3 ...

In Section 6.3 there are more details on CEDVAL, as well as references to a number of wind tunnel studies concerning building effects and dispersion models.

4 Dispersion models

There are numerous models that are applied for modelling of odour. Many of these models were developed for atmospheric dispersion calculations in general, and are not specifically designed to address odour problems. Nevertheless, they form the core of odour models and may also have other qualities that are of interest in the present context.

Models as classified by their role

The focus in the present review will be on models and model components that are of particular interest for the current project. Such models are

1. *General-purpose models* that are well established and that contain elements of particular interest in relation to the current project. An element of primary interest is the way that models handle building downwash effects. A subsequent chapter in the present report deals exclusively with the question of building downwash.

2. Models that are *applied for odour assessments* in other countries.

3. Models that are well *suited for handling concentration fluctuations*. Many such models are so computer-intensive that their practical applicability is limited.

4. Models for *special purposes*. In the present context we discuss micro-scale models for resolving building effects; such models can be useful as an aid when developing operational models.

The discussion in the present report does not go in depth with the models. In the course of the current project it is the plan to work more intensively with some of the models and with selected model components. Therefore, a more in-depth treatment of certain models will be a part of the later reports and publications within the project.

The next section presents an alternative way to classify models compared to the one above.

However, the present chapter is structured corresponding to the four categories listed above, which emphasises *the role* of models. For each of the four roles there is a section in the chapter.

4.1 Model principles

Models classified by modelling principle

As an alternative to the above way of classifying models, they can be classified according to their underlying principle. Although we have not used that approach to structure the subsequent discussion, such a perspective is sometimes useful. We will here present some main classes of models, defined according to their working principle.

- Gaussian plume models.
  Assumes that dispersion takes place in plumes with a straight

centerline. The plume shape is assumed to be Gaussian.
Example: The Danish OML model (Section 4.2.4).

- Gaussian puff models.
  In a puff model, the pollutant is assumed to be emitted as a large number of puffs in rapid succession. This allows the plume to follow a curved path, and the emission may be non-stationary in time. An example is the RIMPUFF model, which is designed to handle problems with nuclear accidents (Thykier-Nielsen et al., 1998). Puff models are not discussed in detail here.

- Lagrangian particle models
  In a Lagrangian model, a large number of virtual particles are released, and their fate is followed and summarised. According to the Lagrangian approach, the virtual particles follow a prescribed wind field modified by turbulence, and the model computes their spatial trajectories.
  Example: AUSTAL2000 (Section 4.2.3).

- CFD (Computational Fluid Dynamics) models
  A very large number of CFD models exists, among them sophisticated commercial codes for all kind of technical fluid dynamical and transport problems (for references see e.g. http://www.cfd-online.com/). Some CFD models are applied for atmospheric boundary layer flows. In this context also the term *prognostic wind field model* is used. There are CFD *flow* models, and some (example: Miskam; Section 4.5) can also handle *dispersion*. These models are based on numerical solution of the governing fluid flow and dispersion equations.

- Diagnostic wind field models.
  Example: TALdia (Section 4.2.3).

4.2 General-purpose models

We will here mention some main features and give references concerning a few, important general-purpose models. First, the models are listed with a very brief explanation of their status; then additional details and references are provided.

- **AERMOD**. AERMOD is a new model developed under the auspices of the US EPA. It is intended to replace the old, regulatory model ISC3, but it has not yet a fully official status. AERMOD belongs to the same class of models as OML, and shares many common features with it. They are both modern Gaussian plume models, belonging to a newer generation of models than ISC3.

- **UK-ADMS**. UK-ADMS is a British model, which is in many respects similar to AERMOD and OML - thus, it is a Gaussian plume model. It is a commercial model marketed by the CERC (Cambridge Environmental Research Consultants).

- **AUSTAL2000**. AUSTAL2000 is a newly developed German model, intended for regulatory use. It belongs to a different class

than the models mentioned above, as it is a Lagrangian particle model.
In 2002, AUSTAL2000 replaced the previously used Gaussian plume model as the official dispersion model for regulatory purposes in the German Technical Instructions on Air Quality Control ('TA Luft').
In 2004, AUSTAL2000 was extended by a procedure to handle odour concentrations, referred to as AUSTAL2000G.

- **OML**. The Danish OML model is a modern-type Gaussian model comparable to AERMOD and UK-ADMS. OML was developed at National Environmental Research Institute (DMU). The standard OML model calculates hourly averages. Since 1990 OML has been used by the Danish authorities and consultants when granting permits to polluting industry. Furthermore, a first version of a short-term concentration fluctuation version of the model, OML-Lugt, has been developed.

Some additional details and references concerning the various models are given in the next subsections.

4.2.1 AERMOD

AERMOD

AERMOD is part of a modeling system with three components: AERMOD itself (a dispersion model); AERMET (a meteorological preprocessor); and AERMAP (a terrain data preprocessor). It does not yet have a fully official status within the regulatory framework of the US EPA. It was first published at the EPA Web site around 1998, and at present there is a Beta test version from 2004 available from the Web site. AERMOD has been the subject of a substantial number of studies.

Documentation

The main documentation of AERMOD is the *AERMOD Model Formulation Document* (Cimorelli et al., 2004b) and the *AERMOD user's guide (EPA, 2002)*, both available from the AERMOD Web site
http://www.epa.gov/scram001/tt26.htm#aermod

The latest version of the documentation pertains to *AERMOD Beta Test version 04300 with PRIME*, which was published in 2005. A short version of the Model Formulation Document is submitted for publication (Cimorelli et al., 2004a), and is likely in future to become the main reference for AERMOD.

History

The first Beta version of AERMOD from 1998 did not include any algorithm for building effects. A separate model addressing building effects, PRIME, was developed during the late 90's. It was included in the old regulatory model, ISC3, resulting in an integrated model called ISC-PRIME. Later, PRIME has been included in AERMOD with a first beta version published in 2002 (more details in Section 5.4.2).

Evaluation studies

There is a growing body of literature on evaluation of AERMOD. Several evaluation studies have been performed under the auspices of the US EPA. A main reference in this context is the report *AERMOD: Latest features and evaluation results (EPA, 2003)*, which provides an overview of the evaluation studies. A total of 17 data sets were used for evaluation of AERMOD. Ten of these do not include building downwash, while seven do. Approximately half of the studies were used for development, while the other half was used for subsequent evaluation.

According to the reported results, AERMOD performs better than ISC3 for data sets representing situations without building downwash. For most data sets involving building downwash, ISC-PRIME and AERMOD-PRIME exhibit similar performance; however, there is one data set with superior AERMOD results (Alaska North Slope).

A major source of information on work concerning intercomparison and evaluation concerning AERMOD is the series of International conferences on *Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes* (www.harmo.org). Many of the references mentioned here are based on presentations given at these conferences.

One such study is the one by Hanna et al. (2001). The authors assess the performance of ISC3, AERMOD and ADMS against experimental field measurements. They conclude that the new models perform better than ISC3, which is highly overpredicting for certain data sets.

The authors find that for the various data sets, sometimes AERMOD performs better than ADMS, and sometimes the roles are reversed, with the overall tendency that ADMS performs slightly better than AERMOD.

Several British studies involving AERMOD have been presented during the Harmonisation conferences (Hall et al., 2001). Some of these have been intercomparison studies, investigating model behaviour under various conditions (for AERMOD, ADMS and ISC). It has proved difficult to identify consistent patterns in the behaviour of the three models. In a comprehensive report by the same group of authors (Hall et al., 2000), they state that the 'advanced' models (AERMOD and ADMS) should be the preferred models for regulatory studies. However, it should be recognised that atmospheric dispersion models are imperfect and, for the 'advanced' models especially, still subject to scientific uncertainty and further development.

4.2.2 UK-ADMS

UK-ADMS

UK-ADMS is a British model, which is in many respects similar to AERMOD and OML. It is a commercial model marketed by the CERC (Cambridge Environmental Research Consultants), and it has a relatively wide usage in the UK.

Technical specification documents

The Web site of CERC contains substantial technical documentation for the model. A User Manual and approximately 25 "Technical specification documents" – as listed next – are available from

http://www.cerc.co.uk/software/publications.htm :

Technical specification documents of the ADMS:

- Standard Properties in ADMS 3.1
- The Met Input Module

- Output Specification for Mean Concentration and Deposition Fluxes
- Calculation of Long term Statistics
- Calculation of Exceedences Using the Fluctuations Module
- Boundary Layer Structure Specification
- Plume/Puff Spread and Mean Concentration Module Specifications
- Plume Rise Model Specification
- The Fluctuations Module
- Averaging Time and Fluctuations in ADMS Versions 1 and 2
- Concentration Fluctuations in ADMS 3.1, Including Fluctuations from Anisotropic and Multiple Sources
- Complex Terrain Module
- Coastline Module. The Thermal Internal Boundary Layer
- Modelling of Building Effects in ADMS
- Sources for Radioactive Decay Data
- Modelling Radioactive Decay
- Modelling Wet Deposition
- Modelling Dry Deposition
- Simple Chemistry
- Calculation of g-Ray Dose rate from Airborne Activity
- Multiple Sources, Species and Particle Sizes
- Implementation of Area, Volume and Line Sources
- Plume Visibility
- Time Varying Releases

In addition, a number of evaluation studies are available on the site. Some of these have been summarised by Walsh and Jones (2002) – see Section 5.4.3 (on ADMS and PRIME).

4.2.3 AUSTAL2000

An overview of AUSTAL2000 is given by Graff (2002).

AUSTAL2000 - a Lagrangian particle model

AUSTAL2000 is a Lagrangian particle model. This type of model tracks point-like particles representing a trace species on their path through the atmosphere. The particles travel with the mean wind and are additionally subject to the influence of turbulence. The effect of the turbulence is modelled by adding an additional random velocity to the mean motion of each particle. This random velocity is a function of the turbulence intensity. The concentration distribution is determined by counting the particles in given sampling volumes and is expressed as mean values over the volume elements and time intervals.

AUSTAL2000 includes a diagnostic wind field model (TALdia) that accounts for the influence of buildings and complex terrain.

Documentation

The technical documentation of AUSTAL2000 (Janicke, 2004) as well as the code itself is available from the Web site www.austal2000.de . The code is written in the language C, and is free under the GNU public license agreement. The documentation consists of a User's Guide (in German). The Web site further contains a substantial number of sample computations.

The modelling principle of AUSTAL2000 is completely different from that of OML, AERMOD and UK-ADMS, which are all Gaussian models. An advantage over the other models is that a Lagrangian model does not assume that the pollution plume moves along a straight line, such as Gaussian models inevitably do. A disadvantage is the very high computational requirements for this model type.

Because the model is so different from OML it cannot be used to provide 'building blocks' that can be used directly in OML.

4.2.4 OML

OML

The OML model is in widespread use in Denmark for regulatory purposes. The model was developed at NERI (Berkowicz et al., 1986; Olesen et al., 1992; Olesen, 1995a).

The OML model is comparable to AERMOD and ADMS. Evaluation studies include those of Berkowicz et al. (1988), Olesen et al. (1992) and Olesen (1995b).

A model version, suitable for computing short-term concentration fluctuations, has been developed in a first version (Løfstrøm et al., 1994; Løfstrøm et al., 1996). It is designated OML-Lugt, and it consists of a module for short-term concentrations, built into the conventional OML model. Through inclusion of this module, OML has the potential for better handling of odour problems than most regulatory models. E.g., AERMOD has no particular provision for odour problems.

The OML model is a fast model, well suited for regulatory purposes. It has a user interface, which makes the model easy to use for the large number of non-expert users in Denmark.

There are known limitations of the current approach to modelling of building effects (see Section 5.2), and it is an aim of the present research project to improve upon that problem.

For users in Denmark, the OML model has the advantages compared to other models that it is integrated in Danish regulations, has a well-established user community, and that it is supported nationally. Thus, there exists a common base of reference between the user community and the authorities.

4.3 Models applied for odour assessments

A recent international conference on "Environmental Odour Management" (Cologne, Nov. 18-19, 2004) brought together an international group of experts working on legislative, administrative level as well as researchers and consultants working with odour assessment. The conference proceedings (VDI, 2004) provide a comprehensive overview of present practice and on-going development in various countries, and they constitute a major source for the information presented in the following.

Relatively few countries have a model that has been designed specifically for odour assessments. Countries, which have emphasised work on odour modelling, are Germany and Austria.

4.3.1 Germany

AUSTAL2000G

In 2002, a new model was introduced for regulatory purposes in Germany, namely AUSTAL2000. In 2004, AUSTAL2000 was extended by a procedure to handle odour concentrations; the resulting model is referred to as AUSTAL2000G (G for "Geruch", i.e. odour). Both AUSTAL2000 and AUSTAL2000G are 'state of the art' Lagrangian particle models. AUSTAL has been criticised for its large calculation times of several hours.

AUSTAL2000G is described briefly by Janicke et al. (2004), and there is a Web site for the model at www.austal2000g.de. The source code for the model is public under a non-commercial GNU licence.

When developing AUSTAL2000G, two options were considered concerning the estimation of odour fluctuations:

A. a meandering plume model

B. a simple empirical function based on the averaged (1-hour) plume.

Sensitivity analysis and comparison with field data and wind tunnel data led to the recommendation of approach *B,* using a factor of 4 on the hourly mean values to account for the concentration fluctuations (Janicke and Janicke, 2004a; Janicke and Janicke, 2004b). However, we – the current project group at NERI – consider it problematic to use a single universal factor, and find that the question warrants further analysis - see also Section 4.3.2.

Other sophisticated odour dispersion models (as e.g. NaSt3D) are used in Germany for research, but are seldom applied for practical assessments or in the consulting business. A systematic validation with measurements has not yet been undertaken.

NaSt3D

NaSt3D is a model, which can be used in either a Eulerian mode or as a Lagrangian particle model. It is briefly described in a conference contribution (Boeker et al., 2001), but the available documentation for the model does not permit a proper understanding and evaluation of the model.

There is a Web site for the related model NaSt3DGP
http://wissrech.iam.uni-bonn.de/research/projects/NaSt3DGP/index.htm
with a User's Guide (Griebel et al., 2004) that describes the numerical aspects of the code (discretization etc) and the use of it. NaSt3DGP is a free downloadable newer version of NaSt3D, which however does not contain the option of a Lagrangian particle model. NaSt3D does not seem to be able by itself to take into account meteorological and physical features such as stability and plume rise, but must have input specified in detail. The model is highly computer-intensive, but can be run on parallel computers (e.g., a cluster of 128 CPU's) to speed up computations. The NaSt3D code was developed at the University of Bonn, Institute for Numerical Simulation, and has been applied for odour modelling.

GERDA

A completely different kind of model is the PC-program called GERDA (Lohmeyer et al., 2004). It was developed in a recent pilot project. GERDA is intended as a screening tool for licensing authorities, so they can determine whether detailed investigations for a given source are required. At the moment GERDA includes only industrial sources, but extensions to other sources are planned. GERDA contains a module for odour emission estimation. A method that reduces the high calculation times of the standard AUSTAL 2000G applications from several hours to about 12 minutes is under development and will be included in GERDA.

4.3.2 Austria

AODM model and separation distances

In Austria, a substantial body of work on odour modelling has been undertaken, based on the Austrian Odour Dispersion Model (AODM). Much of the work has been on examining procedures for calculating separation distances between livestock farms and residential areas. Such procedures exist in many countries, but they are usually empirically based and often neglect potentially important aspects. Piringer and Schauberger (1999) compare such procedures for Austria, Germany, Switzerland and the Netherlands, and an attempt is made to produce a more accurate estimate based on the AODM model. Such work is pursued in subsequent publications (e.g. Piringer et al., 2004).

Conversion from mean to peak values

The AODM model, which forms the basis for these investigations, consists of three modules: One for odour emission from livestock, a second for estimation of concentrations by a Gaussian model based on a traditional discrete stability classification scheme, and a third to transform the mean value to an instantaneous value, using a conversion factor. In many procedures for odour estimation, use is made of such a conversion factor to transform mean concentrations (hourly or half-hourly) to short term peak concentrations (with an averaging time on the order of a few seconds to a minute).

In Denmark, for regulatory applications a factor of 7.8 is frequently used. It is an extreme simplification always to use the same constant factor, as this factor should depend on stability, distance from the source, as well as on source characteristics. Much of the work undertaken by the Austrian group has addressed this factor, mainly in respect to dependence on stability and distance (not source characteristics – see also Section 4.4).

However, sensitivity studies (Piringer et al., 2004) show that there is not any firm base for calculating the conversion factor within the AODM model. The result is sensitive to parameterisation inside AODM, and this parameterisation is not well established. This suggests that a more detailed or a different approach would be more appropriate. Actually, use of a factor can be entirely avoided by applying the approach of OML-Lugt (Løfstrøm et al., 1996; Løfstrøm, 2000)

4.4 Models for concentration fluctuations

Short-term concentration fluctuations

The time resolution of most dispersion models is one hour. Within that hour, odour concentrations will fluctuate widely around the hourly mean value. This is a fundamental feature when a plume is spread and diluted. The concentration variance is not constant. It changes with meteorology, distance, emission height above ground and source configuration (exhaust pipe diameter, building geometry etc. See Jørgensen and Nielsen, 1999; Lewellen and Sykes, 1986; Mylne et al., 1996; Nielsen et al., 2002; Sykes, 1998; Wilson, 1995).

Ideally, one should use advanced atmospheric dispersion models capable of estimating fluctuations in short-term odour concentrations, in order to provide the best base for assessment of the human perception as described in the introductory chapter. These concentration levels ought to be combined with frequency statistics calculated for a longer time period (month or a year) in order to provide a complete assessment. Unfortunately, only few dispersion models are able to estimate short-term concentrations, and most models use instead highly simplified and uncertain methods to convert the commonly estimated one-hour average concentrations to short-term averages.

Constant factor models

The method most often used for estimating the peak concentration from an hourly mean value is simply to multiply the hourly mean by a constant conversion factor. The principal formula used is

$$C_2 = (\frac{t_1}{t_2})^p \; C_1 \qquad (4\text{-}1)$$

where C_i is the mean concentration over averaging time t_i and p is an empirical constant in the range 0.2 to 0.5 (Venkatram 2002).

For instance, when converting from 60-minute to 1-minute averages with p=0.5, the conversion factor is

$$(\frac{t_1}{t_2})^p = (\frac{60}{1})^{0.5} = 7.75 \qquad (4\text{-}2)$$

This conversion factor is used in Denmark for many regulatory applications. As previously mentioned, AUSTAL2000G uses a factor of 4.

Slightly more advanced models use a conversion factor, but take the atmospheric stability into account. Such models are those of Schauberger and Piringer (2004) with the exponent p between 0 and 0.68, and that of Schauberger et al. (2000), which includes also a (theoretical) dependence on distance.

However, Venkatram (2002) shows that equation (4-1) cannot be justified, and that it is not meaningful to use this equation to estimate a single short-term peak. Instead, the concentrations should be described by concentration distributions. This emphasises that the validity of the factor of 4 used for estimating the influence of short-term concentrations in AUSTAL2000G can be questioned. Similarly implications goes for the currently used Danish regulatory model for odorous industry, which uses a conversion factor of 7.8.

There are, however, other approaches than that of a conversion factor.

Meandering plume models

Meandering plume models split a time averaged plume – such as normally modelled - into an instantaneous (smaller) plume that meanders (moves from side to side and up and down). The movement of the instantaneous plume gives the concentration fluctuations for estimating e.g. the concentration variance (Wilson, 1995; Sykes, 1998).

Semi-empirical model

A semi-empirical short-term concentration fluctuation model that builds on another approach has been developed at the Danish National Environmental Research Institute (NERI). The model is OML-Lugt (*Lugt* is the Danish word for odour) (Løfstrøm et al., 1994; Løfstrøm et al., 1996). The model is based on the principles of a Gaussian concentration fluctuation model that was developed on wind tunnel data by Wilson et al. (1985). OML-Lugt has been developed further, using data from full-scale field experiments and some newer principles based on the meandering plume model (Wilson, 1995; Sykes, 1998) .

OML-Lugt consists of a module for short-term concentrations, which is built into OML. The module takes into account many parameters that are known to influence concentration fluctuations: meteorology, distance, emission height, outlet diameter, and buildings. The module is formula-based and can be implemented into one-hour-mean plume models that already contain information on the dispersion parameters σ_y and σ_z, as well as on micro-meteorological parameters. The model is designed for fast and operational use on hourly meteorological data for e.g. a complete year.

The model calculates the spatial distribution of concentration fluctuation intensities (rms/mean) in the plume from a point source. The form of the intensity distribution is closely connected to the mean plume dispersion parameters σ_y and σ_z. The level of the fluctuation intensity depends on the turbulent length scales and the source diameter. The intensity and the mean concentration at a certain location then determine the form of the probability density function (*pdf*) of the concentration fluctuations. The *pdf's* are well approximated by 'clipped'-normal pdf's – here the term 'clipped' refers to the fact that the portion of the *pdf* that correspond to negative concentrations actually refers to zeroes. In this way the statistical concentration fluctuations are determined within any hour of the calculation period.

Lagrangian particle tracking models

Other types of models require intensive and long computer calculations and are mostly used for research purpose. Among such models are (Wilson, 1995) *Lagrangian particle tracking models* that tracks thousands of particle pairs. The models use a description of single particle random movement and the distance-correlated movement of the particle pairs. It is necessary to use pairs in order to describe the fluctuations correctly.

The concentration fluctuation intensity calculations in UK-ADMS are based on this principle; various model statistics are estimated using clipped-normal pdf's that are determined by the concentration intensity and mean (Dyster et al., 2001).

4.5 Models for special purposes

In Chapter 1 we listed three methods to obtain data for model verification:

- Field measurements
- Data from wind tunnels;

- Data obtained by more detailed models than the one being investigated.

CFD models have a role in verification of simpler models

The two first methods were treated previously (in Chapters 2 and 3). The third concerns the possibility that numerical models - e.g. Computational Fluid Dynamic models - are employed to study a limited number of representative episodes for complex building and source configurations. Such CFD models are suited to validate empirical parameters used in simpler models.

In section 5.3 on building effects there is further discussion of advantages and disadvantages of CFD models. Here, we will just introduce the MISKAM model, which is a model that we plan to use within the current project. MISKAM is a German state-of-the-art model, which is well documented, and which has been used for several years at NERI.

MISKAM

MISKAM (Eichhorn, 1989) is a 3-dimensional prognostic flow and dispersion model that is designed to describe in detail the flow around groups of buildings. It is widely used in Germany and in some other places in Europe, altogether in more than 50 institutions. The model has been validated with several CEVDAL data sets (Section 6.3) according to the Draft of the German Guideline VDI 3783 (VDI, 2003). The latest version 5.0 of MISKAM (Dec. 2004) was extended to account for semi-permeable obstacles as trees and vertical plumes. Both of these features are relevant for odour dispersion, since trees and vertical exhaust plumes are often relevant for agricultural sources.

The way MISKAM works is that in a first step, it calculates the stationary wind fields in an Eulerian rectangular grid. In a second step, the dispersion is calculated using an advection-diffusion approach. As all Eulerian grid models MISKAM contains the problem of numerical diffusion. MISKAM is only validated for neutral stratification, although a simple parameterisation for stable flow is included.

Documentation of MISKAM itself as well as the user interface and the performed validations are included in the program package and can also be found under:
http://lohmeyer.de/Software/winmiskam.htm

5 Building downwash

Outline of the chapter

The present chapter is devoted to a discussion of how to parameterise the effect of building downwash. This topic will receive much attention during the further phases of the current project.

First, we present a general description of the phenomena of building downwash. Next, we outline the current approach used in the OML model.

Building effects can be simulated rather precisely by two types of advanced modeling techniques:

- Physical modelling in wind tunnel (Chapter 3)
- CFD models

The advantages and disadvantages of wind tunnel modelling have been treated in Chapter 3, and some wind tunnel data sets relevant for building downwash modelling are presented in the Chapter on data sets (Section 6.3).

Here, in Section 5.3 of the present chapter, we discuss the role of CFD models to study building effects.

Finally, we discuss the use of simpler, analytical building downwash models (UK-ADMS and PRIME) that can be applied for regulatory modelling.

5.1 Physical description

If a building or another large obstacle is situated close to a stack, plume dispersion can be disturbed. This can have a substantial effect on the resulting ground-level concentrations.

Turbulence zones around a building

When the airflow meets a building, it is forced up and over and around the building. This not only modifies the streamlines of the airflow, but also has an effect on the speed and turbulence of the air. The region where these effects are significant is usually called the *Far Wake zone* (or the *Turbulent Wake zone)* – see *Figure 1*.

On the lee side of the building, the flow can separate, thus forming a closed re-circulation zone. This is the *Near Wake recirculation zone* (or *Cavity zone)*. In this zone the wind speed is significantly reduced, but due to intensive turbulence the mixing is very rapid. If a plume becomes caught in the cavity, very high concentrations can result, with the highest values close to the leeward facade of the building.

On the upwind side of the building, an *Upwind Recirculation zone* (or upwind cavity) exists.

Over the roof the approaching flow separates, thus forming a *Roof cavity*. The flow may reattach to the roof, depending on geometry.

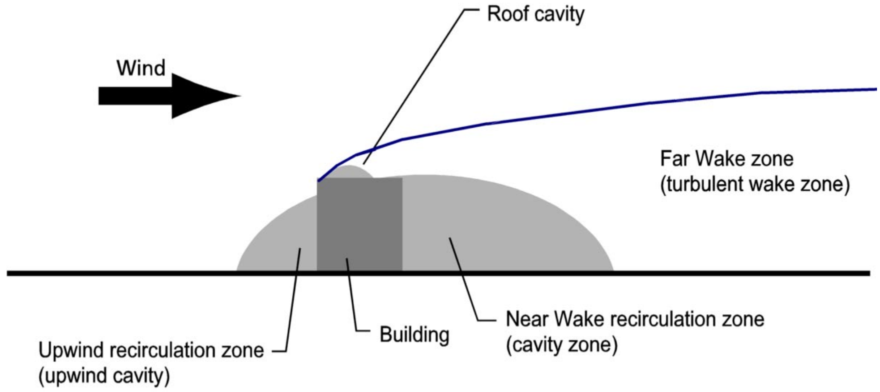

Figure 1 Schematic illustration of the effect of a building on the airflow.

If a plume enters the Far Wake zone, its trajectory will more or less follow the streamlines of the airflow in the zone. Close to the building, in the air above the building (i.e. in the Far Wake zone) the streamlines will have an upward slope and thereby the plume in this area will be lifted up. At some distance from the building the streamlines will have a downward slope and this will bring the plume closer to the ground. Increased turbulence in the wake will result in an increased dispersion and dilution of the plume material, and the final effect on the ground level concentrations will depend on the combined effect of the increased dispersion and reduced plume height.

Reviews of building effect studies

Comprehensive reviews of many building effect studies are available in Meroney (1982) and Hosker (1984) and in a more recent publication by Canepa (2004). Colville et al. (1999) review models for calculating concentrations subject to building effects. A detailed review covering the most recent knowledge of the problems related to flows and dispersion in the vicinity of groups of buildings is presented by Robins and MacDonald (2001).

The impact of buildings on transport and dispersion thus depends on the building characteristics, on the location of the source with respect to the building, and last but not least, on the source characteristics itself.

Interaction with plume rise

Often a plume from an outlet is subject to plume rise. Plume rise can take place because the plume is warmer than the ambient air, and/or because the plume has a vertical exit velocity. Plume rise acts to increase the effective release height and can thereby contribute to a substantial reduction of the maximum ground level concentrations. Plume rise can also have significant influence on how a plume will interact with the nearby buildings. Sufficiently large plume rise can effectively bring the plume out of the building's influence zone, or it can reduce the portion of the plume that is captured in the zone. However, the interaction between plume rise and the building effects is twofold. The increased turbulence and thereby dispersion in the building's influence zone will generally result in a reduction of the plume rise. This will tend to give increased maximum ground-level concentrations, but the final result will depend on the combined effect of the reduction of the plume height and the increased dispersion of the plume material.

5.2 Current approach in OML

The current versions of the OML model (OML-Point 2.1 and OML-Multi 5.0) use a procedure for building effects which was developed in the 1980's, and which is based on work by Schulman and Scire (1980). A more detailed description of the OML procedure is given by Olesen and Genikhovich (2000). In that report, results of model evaluation on data from comprehensive wind-tunnel experiments (Thompson, 1993) are presented and the shortcomings of the present procedure are discussed.

The building influence, as modelled in OML, has two main effects:

- it increases the initial dilution of the plume, and
- it decreases the plume rise.

Concept of "Initial dilution radius"

The effects of a building on a dispersing plume are modelled by assuming that the plume has an initial dilution radius, R_0. The radius R_0 is used to calculate the initial enhanced dispersion parameters (σ_y and σ_z), and to reduce the plume rise (The dispersion parameters in Gaussian models are a measure of plume width).

Domain of influence

When the effect of the presence of buildings is evaluated in the OML model, the underlying assumption is that a building of (computational) height H_B creates a domain of influence, which extends $2H_B$ downstream of the building. If a stack is placed within this domain, dispersion from the stack may be affected by the building. If, on the other hand, the stack is placed outside of the influence domain, the plume remains unaffected.

Significance of plume height at the edge of the influence domain

Plume height at a distance $2H_B$ downwind of the building is evaluated (assuming an undisturbed plume) in order to determine the amount of building influence. If the plume height at that point is greater than 3 H_B, building effects will be ignored. If, on the other hand, it is smaller, modifications are imposed upon the plume rise and the dispersion coefficients through the initial dilution radius (*Figure 2*, further details can be found in Olesen and Genikhovich (2000)).

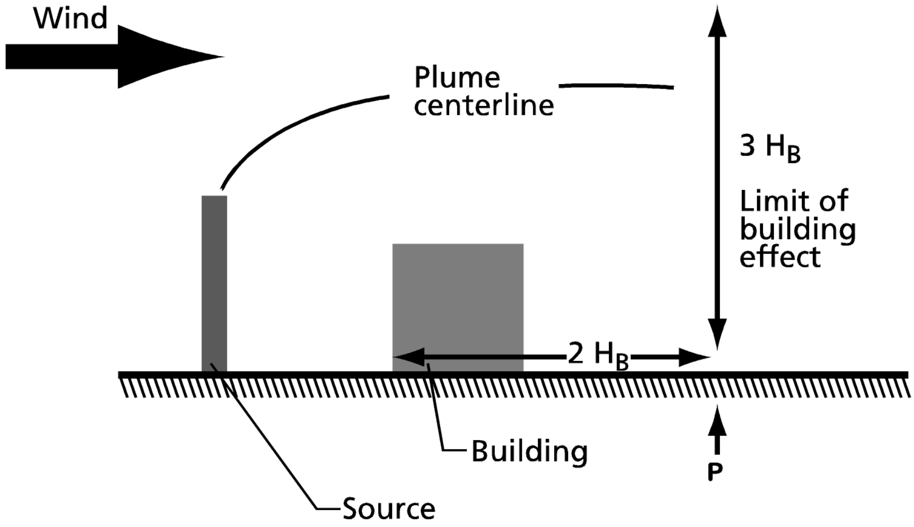

Figure 2 OML criteria to determine whether the plume is affected by a building. Plume height is evaluated at the point P. If the plume height is less than 3 H_B, the plume is affected by the building.

Objective of current procedure

The building downwash procedure in the current OML model is based on simple semi-empirical methods, whereas in reality, aerodynamics in the wake of a building is an extremely complex matter. The primary intention behind this building effect algorithm was to provide concentration estimates applicable for distances beyond, say, ten building heights downwind. With the current procedure, concentration estimates close to buildings have greater uncertainty.

The original main purpose of OML was to provide an effective tool for estimation of air pollution from large industrial sources. With this in mind the focus was on modelling plumes from high stacks with significant buoyancy plume rise. An early test of the model on specially collected monitoring data from Danish largest power plant, Asnæs at Kalundborg, has proven the models applicability for such application (Berkowicz et al., 1988). It was shown that the building's impact on plume dispersion from the power plant stacks could be adequately predicted by the model, and that the main impact was related to lowering of the plume rise.

Limitations of current OML algorithm

The main limitations of the current OML building algorithm can be summarised as follows:

- OML assumes that buildings do not affect concentrations if the stack is further than 2 H_B upwind or downwind of the building. This assumption seems to represent a severe problem.
- OML does not distinguish between a very "wide" building (across-wind width) and a moderately wide building (whereas OML does give "narrow buildings" - i.e., buildings with height greater than width - special treatment). This problem seems to be of moderate importance.
- OML does not account for the "depth" of a building (the along-wind length of the building). This problem is of less importance than the problems mentioned above.

- The behaviour of the plume centre line is greatly simplified. Thus, if there is no plume rise, the height of the plume centre remains unaffected by the building.
- There are discontinuities in the present OML algorithm (the discontinuities occur when the stack is moved relative to the building).

The report by Olesen and Genikhovich (2000) outlines a proposal for new algorithms to determine the effect of building downwash, based on the ideas of Genikhovich and Snyder (1994). A procedure based on these principles is likely to be a considerable improvement over the current procedure. However, a very substantial work would be required for a full development of all necessary parameterisations. Within the current project, we will first consider less costly ways of improving the building algorithm, based upon existing methods - c.f. Section 5.4.

5.3 Computational Fluid Dynamics Modelling (CFD)

CFD technique

CFD models are based on numerical solutions of the governing physical flow and turbulence equations (Navier-Stokes equations). There exists a variety of such models, but the type of CFD models that have gained the most wide application within micro-scale atmospheric problems are the so-called k-ε models (Launder and Spalding, 1974; Rodi, 1995). The technique has been known and used since the early 70's, and numerous modifications and improvements have been introduced to adapt these models to conditions involving flow around buildings (see e.g. Lakehal and Rodi, 1997). The main advantage of the CFD technique is here that a CFD model does not require implementation of any special building algorithm. The impact of buildings on the flow and turbulence is an inherent part of the basic physics of the model. A review of the practical aspects related to applications of CFD models for studies of building impacts is given by Robins and MacDonald (2001).

Gridsize and computer requirements

CFD models involve numerical solutions on a computational grid, which for applications related to building effects, must have a size of the order of 1 m or less. This again implies that the number of the computational grid points, even for a simple case, can be very large. As a consequence, the computational time (CPU-time) required for CFD simulations is usually quite excessive. One single realisation of flow conditions around buildings can take hours, or in a more complex case, even days.

Advantages and drawbacks of CFD modelling

The main advantage of CFD modelling is the large flexibility in application conditions, and the high degree of details that can be resolved by the models.

The main disadvantage of CFD models is the very high computational time, and the fact that there is still large uncertainty in the results provided by the models. For some of the models quite successful results are reported for particular applications (e.g. Hanna et al., 2004) but large discrepancies are evident in many other studies (Hall, 1997; Ketzel et al., 2001). As stated in the review by Robins and MacDonald (2001), the most likely impact of CFD simulations is as an alternative or supplement to wind tunnel modelling. This can ensure inter-comparability of the results and further improvement of the models.

Use of CFD models poses high requirements to the modeller, because a wide range of user inputs is needed (grid details, boundary conditions – cf. Colville et al. (1999)). The variability in the input conditions, the choice of the CFD model and the different turbulence closures can result in large differences in model results for the same problem (Ketzel et al., 2001).

A newly established COST Action, COST 732 (http://cost.cordis.lu/src/pdf/732-e.pdf), has as the main objective to improve and assure the quality of micro-scale meteorological models that are applied for predicting flow and transport processes in urban or industrial environments. The Action will aim at establishing the basis for implementing measures to assure that environmental assessments based on modelling are considered sound, reliable and accurate. This action is related to the current project, and NERI is represented in the Management Committee of the action.

5.4 Analytical models

In spite of increased computer power and improvements in the CFD modelling techniques, in the foreseeable future regulatory modelling is expected still to be based on simpler analytical models similar to OML.

Concerning modelling of building impacts on plume dispersion, two particular methods have recently gained special interest in the modelling community. These are:

- The Building Effects Module of UK-ADMS
- The Plume Rise Model Enhancements – PRIME

Both models have several common features but also differ in some details.

5.4.1 The Building Effects Module of UK-ADMS

The Building Effects Module of UK-ADMS (Robins and Apsley, 2003) is based on the model of Hunt and Robins (1982). Further references can be found at the Web site of CERC, http://www.cerc.co.uk/software/publications.htm and in a note by Robins (2000).

In ADMS, the interaction of the plume with a building is calculated taking into account the position of the source with respect to several zones defined in the area around the building. The building algorithm is only invoked whenever a plume enters one of the specified zones.

Two-plume regime downwind of recirculation zone

The key feature of the ADMS building model is the treatment of the plume in the case when it partially or completely enters into the Near Wake Region (the recirculation zone). The portion of the plume in this zone is assumed to be homogeneously mixed within the zone and to form a new volume source. This results in a two-plume regime downwind of the recirculation zone. The dimensions of the different zones depend on the dimensions of the involved building (actually, an "effective" building in the case of a complex building structure), but also on the angle between the approaching flow and the building face. The most pronounced flow modification (downwash) takes place when the approaching flow is at an angle of 45° with respect to the building face, while it decreases in the case of a perpendicular flow.

The Building Effects Module of UK-ADMS is a part of the commercial modelling system UK-ADMS and cannot be easily transferred to other dispersion models.

5.4.2 The Plume Rise Model Enhancements – PRIME

In the US, a new Gaussian dispersion model, PRIME, was developed for plume rise and building downwash in the late 1990's (Schulman et al., 2000).

PRIME: Integration with ISC and AERMOD

PRIME was included in the old regulatory model, ISC3, resulting in an integrated model called ISC-PRIME. Later, PRIME has been included in AERMOD with a first beta version (AERMOD-PRIME) published in 2002. In April 2005 a second beta version was published. Because of the history of PRIME, some of the documentation of PRIME is associated with ISC-PRIME. The original PRIME made use of Pasquill-Gifford dispersion parameters, which is different from the methodology used in AERMOD (and OML). When integrated into AERMOD, PRIME has been modified to make use of AERMOD's methodology to parameterise dispersion.

PRIME is actually a separate dispersion model. The concentrations computed by PRIME are used in the wake of a building, and beyond the building, concentrations are gradually adjusted to those computed by AERMOD itself.

Sub-zones

PRIME considers the position of the stack relative to the building, streamline deflection near the building, and vertical wind shear and velocity deficit effects on plume rise. The building's influence zone is divided into several sub-zones, similar to the Building Effects Module of UK-ADMS, but in a somewhat more simplified manner. The plume trajectory and dispersion are calculated explicitly in each of the zones, taking into account the local streamline slope and the turbulence intensity. The plume rise is computed using a numerical solution of the mass, energy and momentum conservation laws. The implementation of the plume rise model in PRIME allows for streamline ascent/descent effects to be considered, as well as the enhanced dilution due to building-induced turbulence. PRIME, similar to the Building Effects Module of UK-ADMS, is using a two-plume approach in the case when a part of the plume is captured by the Near Wake recirculation zone.

The PRIME model is provided as an open-source code, and it should be possible to implement this code in different Gaussian-type dispersion models, such as OML. The difficulties in this respect seem similar to those of integrating PRIME into AERMOD. The issues involved are discussed in the Model Formulation Document (Cimorelli et al., 2004b) as well as in EPA (2003).

5.4.3 Evaluation and intercomparison studies

UK-based studies of ADMS and PRIME

A list of publications and reports covering the evaluation studies of the UK-ADMS model, including the Building Model and intercomparison with PRIME, can be found at

http://www.cerc.co.uk/software/publications.htm.

Walsh and Jones (2002) summarise the outcome of several comparison studies involving ADMS, ISC-PRIME, ISC and AERMOD.

In a pure intercomparison study (CERC, 2000) it was found that the ratio between ADMS and ISC-PRIME predictions were in a range 0.23 to 5.0.

Two studies by the authors of the ADMS model (CERC, 2001a; CERC, 2001b), where ADMS, ISC-PRIME and ISC were evaluated against wind tunnel data, indicate that ADMS performed best in terms of correlation, absolute fractional bias, and normalised mean square error - but not always provided the best mean value.

It is interesting to note that when the building orientation is changed from perpendicular to 45 degrees to the wind direction, ADMS predicts that the maximum ground level concentrations increase, as observed, whereas ISC-PRIME predicts that concentrations decrease which is opposite to the observed trend.

Sidle et al. of the UK Environment Agency (2004) present a model intercomparison based on the same protocol as Hall et al. (2001). However, as the study by Sidle et al. is more recent, it has been possible to include AERMOD-PRIME in the study.

The study reports an interesting case where AERMOD results are very sensitive to the precise location of a building.

Generally, the authors find it difficult to reach generic conclusions regarding implications for the use of the models. AERMOD-PRIME and ADMS 3.1 show significantly different dependence of building downwash effects as a function of wind directions. There is no simple relationship between the predictions with building effects of AERMOD-PRIME and ADMS 3.1 over a range of building geometry.

Sidle et al. find that in unstable conditions, AERMOD Prime predicts lower concentrations than either AERMOD or ADMS 3.1.

The authors recommend that further measurement campaigns or validation experiments be performed to try to address the issues raised by model comparison studies.

US-based studies on PRIME

Evaluation studies of the PRIME model and/or application of PRIME within ISC and AERMOD models are reported by Weil (1996), Paine and Lew (1997; 1998) and Schulman et al. (2000).

A key reference

A short note by Robins (2000) is a valuable resource for further studies of the details of the building algorithms of PRIME and ADMS: The note presents in a tabular form differences between model concepts, tables of data sets used for performance evaluation, and literature references.

Differences between ADMS and PRIME

The differences between ADMS and PRIME have been summarised by Walsh and Jones (2002), who quote Robins as their source. The following differences are important:

Wind direction dependence

- PRIME derives the variation in streamline deflection with wind direction through the effective building dimensions, whereas ADMS additionally uses an explicit dependence on wind direction. This is likely to cause significant differences in the performance of the two models.

Effective building

- PRIME uses a modified form of the EPA BPIP building preprocessor, which is designed to calculate the effective height and projected width for each wind direction and for each stack that leads the highest good engineering practice stack height. ADMS generates the effective building shape and orientation from input building information, and creates an effective building that is normal to the oncoming flow. The orientation is stored so that appropriate levels of streamline deflection can be calculated.

Concentrations in the near wake

- Near wake concentrations models differ, and the ADMS prediction is about twice the value predicted by PRIME; however this is well within the level of uncertainty associated with such predictions.
- In the main wake calculations, differences arise in the treatment of the flow field. (In PRIME there is no allowance for streamline convergence associated with wake decay).
- An integral plume rise calculation is used in both models, however there are differences in the way that discharges are treated in the near-wake. In PRIME, plume rise and entrainment calculations are undertaken for all but passive emissions in the near wake, while in ADMS the plume rise and entrainment calculations are initialised only if criteria related to buoyancy and momentum length scales and source position are satisfied.

6 Selection of data sets for model validation

Scope of the chapter on data sets

The present report has been prepared to set the scene for a project on further development of the OML model, and to serve the subsequent activities of the project. In the course of the project, the project group will make use of various data sets for validating the OML dispersion model, as well as for validating parts of the model.

This chapter presents some data sets that may be relevant, as well as some sources where additional data sets can be identified. The data sets mentioned here are candidates to be used within the current project; eventually, however, only a small number of the data sets will be selected for actual use.

The chapter refers to both field data and wind tunnel data.

Criteria for selecting data sets

The selection of data sets will eventually take place as a compromise between several considerations:

- How relevant are the scenarios represented by the data set?
- Availability and quality of data.
- The amount of data provided in the data set.
- Have other research groups used the data? This counts in favour of using a data set, because it makes it possible to intercompare results and draw upon the experiences gained by others.

The information presented here can serve as help in the process of identifying appropriate data sets for model validation. There are two main sections in the chapter:

- An overview of entry points to data sets (sources of data)
- An overview of potentially relevant data sets.

6.1 Sources of data

Entry points to experiments

This section gives overview of important entry points to experimental data sets.

- In the context of the initiative on *Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes*, the so-called *Model Validation Kit* is being used. This "tool kit" includes data sets and tools for model evaluation that have been widely used internationally. The kit allows intercomparisons between models. NERI is a key player in the context of the initiative, and has had a major role in establishing the Model Validation Kit. Since the emergence of the kit additional tools have emerged, and it is now relevant to incorporate these into the kit. It is the intention to use the kit within the current project, and at the same time improve it. The kit includes some "classic" data sets (Section 6.2.1). The kit is available at
  http://www.dmu.dk/atmosphericenvironment/harmoni/M_V_KIT.htm

- CEDVAL is a compilation of mainly wind tunnel data sets that can be used for validation of numerical dispersion models. The compilation is managed by the wind tunnel research group of the Meteorological Institute at the University of Hamburg (http://www.mi.uni-hamburg.de/cedval/; se also Section 6.3).

- DAM: Data sets for Atmospheric Modelling. A Web site providing information on and access to experimental data sets relevant for dispersion modellers More than 100 data sets are catalogued. The Web site resides at the European Joint Research Centre at Ispra, see http://rtmod.jrc.it/dam/

- Data sets used for validation of other models. Thus, the US model AERMOD and the British ADMS model have been validated against certain data sets. These data sets are potential candidates for inclusion in the present context, and they are specified in Section 6.2.3 and 6.3.

6.2 Data sets

The present section lists data sets grouped into the following categories:

- Field data of general interest
- Data sets including information on concentration fluctuations
- Field data with building downwash
- Field data sets related to stables
- Wind tunnel data

6.2.1 Field data of general interest

The data sets used as part of the Model Validation Kit are of interest because of their "classic" status and widespread use.

- Kincaid
- Indianapolis
- Copenhagen (Gladsaxe).

Furthermore, another "classic" experiment is the Prairie Grass experiment (Barad, 1958).

6.2.2 Data sets including information on concentration fluctuations

- Borex. There were experimental campaigns at Borris, Denmark in 1992, 1994 and 1995 (Ellerman and Løfstrøm, 1999). At the experiments - the so-called BOREX experiments - a tracer gas (SF_6) was released simultaneously with visual smoke from 21-24 meter high masts. Information on concentration fluctuations was measured by lidar.

- Measurements relating to concentration fluctuations collected by the UK Met Office 1987-1992 (e.g. Mylne and Mason, 1991).

- Borsele, The Netherlands
  Release of smoke and tracer from a 57 m ventilator shaft; on some occasions building downwash from a 67 m building downwind of the release point. Lidar and tracer measurements (Scholten et al., 1994).

6.2.3 Field data with building downwash

The US AERMOD model was evaluated with some data sets without building downwash (some of the classic data sets mentioned above). Further, the following data sets with building downwash were used (the data sets listed below are exclusively tracer data sets with a good spatial resolution):

- AGA Flat, Rural, Downwash.
  American Gas Association (AGA) experiments, Texas and Kansas. Gas compressor station stacks. Stack height to building height ratio ranging from 0.95 to 2.52.
  63 hours tracer data, samplers from 50 to 200 m.
- Alaska Flat, Rural Downwash
  Highly buoyant gas turbine, 39-m stack. 44 hours, samples from 20 to 3000 m.
- DAEC Flat, Rural, Downwash
  Duane Arnold Energy Center (Iowa). Non-buoyant releases at heights of 46 m, 24 m, and ground level. Elevated terrain.
  39 releases, samplers at 300 and 1000 meters.
- EOCR Flat, Rural, Downwash.
  EOCR Test Reactor Building (Idaho).
  Non-buoyant releases at 30 m, 25 m and ground level.
  22 hours, samplers from 37 to 1600 meters.
- Millstone Flat, Rural, Downwash
  Millstone Nuclear Power Station (Connecticut).

Slightly buoyant release from reactor and turbine buildings.
36 hours, samples from 200 to 1000 meters.

An EPA report on AERMOD (EPA, 2003) presents an overview of the data sets, and they are available at the AERMOD Web site (see section 4.2.1).

6.2.4 Field data sets related to stables

Roager

- In Denmark, a series of experiments were conducted at a farm at Roager near Ribe. During the experiments, the outlet height was varied. The experiments are described in an internal report by Ellermann and Løfstrøm (1999).

Uttenweiler

- In Germany, a very comprehensive data set has been collected especially designed for the validation of odour dispersion models (Bächlin et al., 2002). The complete data set and project reports are available from the Internet (http://www.lohmeyer.de/eigenedaten.htm and http://www.lohmeyer.de/literatur/1408bericht.pdf).
  The experiment was conducted at a single located pig stable near Uttenweiler. The stable has a base of 30x50m^2, the height of the ridge is about 8 m and a single forced ventilation released in a height of 8.5 m. At 15 single experiments odour measurements accompanied by simultaneous SF6 tracer gas measurements were performed at two cross sections downwind the farm with 11 / 12 measuring points. From these measurements both mean concentrations as well as the characteristics of concentration fluctuations can be deduced.

6.3 Wind tunnel data

A large number of wind tunnel experiments have been performed with the special aim to investigate the impact of buildings on flow and dispersion conditions. They include those of Robins and Castro (1977); Hubert and Snyder (1982); Meroney (1982); Hosker (1984); Foster and Robins (1985); Hosker and Pendergrass (1986); Snyder and Lawson (1994); Macdonald (1997); Mavroidis (1997); Thompson (1993).

Some of the most interesting of those are the following:

Thompson study on Building Amplification Factors

The study by Thompson (1993) on "building amplification factors" has been used for previous investigations of the building algorithm of OML (Olesen and Genikhovich, 2000). They concern buildings of 4 different shapes, where a stack is placed at many locations upwind and downwind of the building.

Wind tunnel data used for ADMS and PRIM

A note by Robins (2000) gives a complete overview of data sets used for performance evaluation of PRIME and ADMS.

CEDVAL

A comprehensive database by the name of CEDVAL is being compiled at the wind tunnel of the Meteorological Institute at the University of Hamburg (http://www.mi.uni-hamburg.de/cedval/). CEDVAL is a compilation of mainly wind tunnel data sets that can be used for validation of numerical dispersion models. The primary goal of CEDVAL is to provide validation data at a higher level of quality than most of the data available can provide so far. All data sets within CEDVAL follow a high quality standard in terms of complete documentation of boundary conditions and quality assurance during measurements.

This database has become very popular among model developers due to its very comprehensive and careful measurements. At the moments data sets the following categories are available:

- flow and dispersion around isolated obstacles (6 data sets)
- flow and dispersion within regular arrays of obstacles (6 data sets)
- odour dispersion modelling (4 data sets)

Uttenweiler simulated in wind tunnel

The data set in the last category investigate the dispersion of tracer-gas released from the ventilation system of a pig barn, under near-neutral stability conditions (Aubrun and Leitl, 2004). For the same pig barn also field measurements were performed (see section 6.2.4). The following effects were studied; influence of wind direction, velocity ratio (source impulse / wind speed), source location and topography. Over 700 time series of concentrations fluctuations have been recorded at different locations downwind the buildings for different wind directions.

7 Conclusions

A tool for the subsequent work

The present report is a tool to be used for subsequent work on model improvement and model assessment, with focus on the OML model.

The report represents a survey of existing literature, models and data sets. It makes it easy to track down the details of the various models and studies.

Studies will include PRIME

In the subsequent work within the current project, various paths will be followed. As a main path, the potential of integrating OML with PRIME will be explored. Apparently, PRIME can be more easily included in OML than the ADMS building effects module, and therefore the PRIME approach will be investigated thoroughly.

Alternatives to PRIME

There are indications that under certain conditions, the ADMS building effects module performs better than PRIME – cf. the discussion in Section 5.4.3 on the behaviour of the models when the building is oriented 45 degrees to the wind direction. This question will be further investigated.

Previous work on the OML building algorithm suggested a conceptually quite attractive way to construct a building algorithm (Olesen and Genikhovich, 2000). This approach will be considered, but the approach suffers from the problem that the required investment in terms of developing effort is expected to be quite large. Therefore, if the PRIME approach is reasonably promising in terms of evaluation results, it may well be the method of choice.

Three approaches to obtain data for evaluation

The previous chapters contain a lot of information on advantages and disadvantages of three approaches to obtain data for model verification: field measurements, wind tunnel simulation, and CFD modelling. This information is summarised in the table on the following pages. All three approaches have limitations, so it is relevant to consider all of them when assessing model performance.

Three approaches to obtain data for model evaluation: Their advantages and disadvantages

	Field measurements	Wind-tunnel experiments	CFD modelling
	Including: a) data from routine monitoring b) data from intensive experimental campaigns		
General	*Advantages*: Represents reality and real meteorological situations. Data from permanent monitoring programmes provide long time series of measurements, covering a broad range of different conditions. *Disadvantages*: Measurements are limited in many respects: few locations with concentration measurements, one or a few source configurations, limited number of meteorological scenarios (for short campaigns).	*Advantages*: Experiments can be performed under well-controlled and repeatable conditions. Very detailed measurements and visualisations are possible. *Disadvantages*: It can be difficult to simulate non-neutral atmospheric stability conditions.	*Advantages*: CFD models are specifically designed for simulations of flow conditions based on solutions of principal physical equations. *Disadvantages*: Detailed simulations require a dense computational grid, which leads to large demands on the CPU-time. Models must be set up specifically to handle each particular problem. Special care must be taken concerning specifications of the computational grid, and different model users may arrive to different solutions due to the high requirements to user inputs.

	Field measurements	**Wind-tunnel experiments**	**CFD modelling**
Dispersion from point sources	*Advantages*: Represents reality For routine monitoring: Meteorological situations cover a broad range of different conditions. *Disadvantages*: The emission rate might not be well defined (routine monitoring). Possible interaction with background concentrations. Difficult to determine the maximum concentration and horizontal extension of a plume. Requires a large number of monitoring stations. Stochastic variability in meteorological conditions leads to large variability in measured ambient concentrations. Point-by-point comparison with model results practically impossible.	*Advantages:* Well defined and repeatable emission and meteorological conditions. Plume concentrations can be measured at a large number of locations and the plume dispersion can be determined with high accuracy. It is possible to make experiments with plume visualisation. *Disadvantages:* It is very difficult to simulate non-neutral dispersion conditions. Wind-tunnel measurements are often restricted to neutral, high wind speed conditions. It is difficult to simulate plume-meandering.	*Advantages:* Well defined and repeatable emission and meteorological conditions. Plume concentrations can be calculated at any specified location. *Disadvantages:* The smallest dimension of a source is always determined by the size of the computational grid. Close to the source the plume concentrations will depend on the size of the computational grid.

	Field measurements	**Wind-tunnel experiments**	**CFD modelling**
Stability conditions	*Advantages*: Represents reality For routine monitoring: Meteorological situations cover a broad range of different conditions. *Disadvantages*: The atmospheric stability conditions must often be determined by using some more or less reliable indirect estimation methods.	*Advantages*: If technically possible, well-defined and controllable stability conditions can be simulated. It is possible to repeat experiments with exactly the same conditions. *Disadvantages*: Only few wind tunnels can simulate non-neutral stratification. In general it is very difficult to simulate non-neutral dispersion conditions. Wind-tunnel measurements are often restricted to neutral, high wind speed conditions.	*Advantages*: Depending on the type of the model it might be possible to simulate a broad range of stability conditions. *Disadvantages*: Most CFD models used for atmospheric dispersion are best validated for neutral conditions (availability of validation data sets). Results from CFD models for non-neutral conditions may contain larger uncertainties than for neutral conditions.
Plume rise	*Advantages*: Represents reality For routine monitoring: Meteorological situations cover a broad range of different conditions. *Disadvantages*: It can be difficult to separate plume rise phenomena from other effects. Single realisations are not repeatable.	*Advantages*: If technically possible, the plume rise can be simulated under well-defined and controllable conditions. *Disadvantages*: In general it is difficult to simulate buoyant plume rise. This requires gas tracers with a density different from the air. Momentum rise is easier to simulate.	*Advantages*: If the physical processes governing plume rise are included in the model, it can be simulated under well-defined and controllable conditions. *Disadvantages*: Requires additional equations for buoyancy and momentum source. Only specially designed models have this capability.

	Field measurements	**Wind-tunnel experiments**	**CFD modelling**
Building effect	*Advantages*: Represents reality For routine monitoring: Meteorological situations cover a broad range of different conditions. *Disadvantages*: It can be difficult to separate effects due to the building impact from other effects. Single realisations are not repeatable. Limited number of source and building configurations.	*Advantages*: Experiments can be performed with and without buildings making it possible to isolate the effects due to building impact. Different building and source configurations can be studied. Experiments can be performed covering a broad range of different meteorological conditions and especially with varying wind directions. *Disadvantages*: It can be difficult to simulate non-neutral atmospheric stability conditions. The upwind turbulence and flow conditions depend on the upwind topography. This may require a significant extension of the modelled area.	*Advantages*: There is no need for any empirical building algorithms. The effect of buildings is simulated directly due to their impact on the flow and dispersion conditions. Calculations can be performed with and without buildings making it possible to isolate the effects due to building impact. Different building and source configurations can be studied. Calculations can be performed covering a broad range of different meteorological conditions and especially with varying wind directions. *Disadvantages*: Detailed simulations of building effects require a dense computational grid, which leads to large demands on the CPU-time. Predictions for the concentration data are less reliable than for flow conditions.

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Danish Summary - Dansk resumé

Inden for rammerne af Vandmiljøplan III pågår et projekt om videreudvikling af en atmosfærisk spredningsmodel (OML).

OML modellen benyttes i forvejen i forbindelse med Miljøstyrelsens Luftvejledning, og den forventes også at komme til at indgå i den fremtidige håndtering af regulering af lugtproblemer og ammoniakdeposition fra husdyrbrug. Der er imidlertid behov for validering og visse forbedringer af modellen, hvis den skal fungere optimalt til disse formål.

Rapporten repræsenterer en vidensyntese. Den giver en oversigt over eksisterende litteratur, modeller og datasæt.

Rapporten indeholder en kort gennemgang af gængse lokal-skala atmosfæriske spredningsmodeller. Imidlertid fokuserer rapporten især på nogle udvalgte emner, som er relevante for det efterfølgende arbejde inden for projektet om forbedringer af OML-modellen i relation til spredning af lugt fra stalde.

Et emne af særlig interesse er den effekt, som bygninger (stalde) har på strømning og spredning. Håndtering af bygningseffekter er et kompliceret problem, og en væsentlig del af rapporten beskæftiger sig med, hvordan spredningsmodeller håndterer bygningseffekter.

Arbejdet med vidensyntesen har ført til, at den såkaldte PRIME-model vil få en fremtrædende plads i det videre arbejde inden for projektet. Det er planen at integrere PRIME i OML. PRIME er en særskilt model beregnet til at beskrive bygningseffekter. Modellen er udviklet i USA i slutningen af 90erne. Fordele og ulemper ved at benytte PRIME i OML vil blive belyst. Der er forskellige alternativer til at benytte PRIME, og principperne fra andre modeller vil også i et vist omfang blive inddraget i arbejdet.

Et andet emne, der er relevant for lugtproblemer generelt, er hvorledes man skal håndtere de komplekse problemstillinger, der knytter sig til lugtopfattelse og administrativ regulering af lugtniveauer. Rapporten indeholder en introduktion til disse emner.

Et tredje emne, som behandles ganske udførligt igennem hele rapporten, er spørgsmålet om at tilvejebringe data som grundlag for modelforbedring og modelvalidering - en form for facitliste, som man kan sammenholde modelresultater med. Sådanne data er nødvendige for projektet, men det er ingenlunde ligetil at skaffe sig et fyldestgørende datagrundlag. I princippet kan man tale om tre typer af data til modelvalidering:

a) Feltmålinger – dels fra eksperimenter og dels fra rutinemæssige overvågningsprogrammer;

b) Vindtunnel-målinger;

c) Data der er tilvejebragt af mere detaljerede modeller end dén, man aktuelt undersøger. Specielt tænkes her på CFD-modeller.

Alle tre data-typer har begrænsninger, så der er grund til at inddrage dem alle, evt. i kombination, når man skal vurdere en models egenskaber. Fordele og ulemper ved metoderne diskuteres, og resultaterne sammenfattes i form af en tabel i konklusionen (kapitel 7).

I øvrigt giver rapporten et overblik over relevante datasæt for modelvalidering. Rapporten omtaler en del datasæt, men det er dog kun nogle af disse, som rent faktisk vil blive gjort til genstand for intensive analyser i løbet af projektet.

Rapporten vil fungere som et værktøj, der bliver benyttet i det efterfølgende arbejde om modelforbedring og modelvalidering.

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541 Regulatory odour model development: Survey of modelling tools and datasets with focus on building effects

A project within the framework of a larger research programme, Action Plan for the Aquatic Environment III (VMP III) aims towards improving an atmospheric dispersion model (OML).

The OML model is used for regulatory applications in Denmark, and it is the candidate model to be used also in future in relation to odour problems due to animal farming. However, the model needs certain improvements in order to be fully suited for that purpose.

The report represents a survey of existing literature, models and data sets. It includes a brief overview of the state-of-the-art of atmospheric dispersion models for estimating local concentration levels in general. However, the report focuses on some particular issues, which are relevant for subsequent work on odour due to animal production.

An issue of primary concern is the effect that buildings (stables) have on flow and dispersion. The handling of building effects is a complicated problem, and a major part of the report is devoted to the treatment of building effects in dispersion models.

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