VALIDATION OF OML, AERMOD/PRIME AND MISKAM USING THE THOMPSON WIND TUNNEL DATA SET FOR SIMPLE STACK-BUILDING CONFIGURATIONS

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ABSTRACT
In 1990 a comprehensive data set on dispersion behind rectangular buildings was compiled in the US EPA wind tunnel. The data set systematically describes dispersion for a variety of building shapes, stack heights and stack locations. These data were originally used to estimate so-called Building Amplification Factor, but the potential of the data set extends much beyond this application. In a recent study we have used this data set to analyse the performance of a number of dispersion models with more or less sophisticated approaches for handling building effects. The models are the Danish OML model, the US AERMOD/PRIME model, and the German MISKAM model.

1. INTRODUCTION
The Danish OML model is a Gaussian plume model, which belongs to the same family of models as AERMOD and UK-ADMS. It is based on boundary-layer theory and not on traditional stability classification. The current standard OML model became operational for regulatory purposes in Denmark already in 1990. The model has recently been reviewed in order to introduce improvements where appropriate (Olesen et al., 2007).

The OML model is equipped with a rather simple building algorithm that allows buildings to modify dispersion only through the effect of plume height and dispersion parameters. It has been considered to replace the OML building algorithm with the PRIME algorithm, which is used by the US AERMOD model. For this reason a study was performed, where the performance of 3 models was analysed for scenarios with buildings present. The models were OML, AERMOD and - for detailed exploration of a limited number of cases - the German CFD model MISKAM.

As basis for the study we used a comprehensive data set on dispersion behind rectangular buildings that was compiled in the US EPA wind tunnel by Thompson (1993). Originally, these data were used to estimate so-called Building Amplification Factor, but the potential of the data set extends much beyond this application.

2. THOMPSON'S WIND TUNNEL DATA
The experimental database of Thompson includes measurements of ground-level centreline concentration distributions for several different combinations of building shapes, stack heights, and stack location relative to the building.

The data set includes around 250 scenarios, where the following parameters vary:

- *Building shape:* Four building geometries were considered, as well as a baseline scenario without building. The buildings were a cube and rectangular buildings with a footprint which is twice or four times the size of the cube. The wind was always perpendicular to the building face. In the present paper we show only results for the cube and the widest building (the width is four times the height).
- *Stack height:* In terms of relative stack height (stack height divided by building height), emphasis was on five values ranging from 0.5 to 3. There are some scenarios for additional stack heights.
- *Stack location:* The location of the stack varied, so there are scenarios with the stack upwind of the building, on top of the building, and downwind of the building. Altogether 17 locations were considered, extending from 14 building heights upwind to 12 building heights downwind. Not all combinations of stack locations with the other parameters were considered.

The data were made available to us in the form of a large number of ASCII files and a data report. We have rearranged the data sets into a few spreadsheets with embedded graphs, so that it is easy to vary parameters and inspect concentration results according to measurement and models. We encourage readers to explore the graphs in the spreadsheets. These can be found through the atmospheric dispersion Wiki http://atmosphericdispersion.wikia.com/wiki/Thompson_Wind_Tunnel_data
The use of a Wiki in this context permits others to contribute with information in future. Many graphs are available in the report by Olesen et al. (2007).

3. THE MODELS
In the comparisons with measured data, the standard version of OML was used (OML version 5.0). Although a new, improved "Research Version" of OML has been developed (Olesen et al., 2007), it was not used in the

present context as it still lacks a building algorithm. For the AERMOD computations, version 04300 (with PRIME) was used. The CFD model MISKAM (version 5.01) was used for a limited number of cases.

4. RESULTS AND DISCUSSION

Figure 1 shows measured and modelled results for four scenarios. The scenarios have been selected because they show some interesting features concerning the effect of building width on measurements and on model results. The characteristic parameters for the four scenarios are:

- The relative stack height is 1 (top row), respectively 1.5 (bottom row)
- The building is a cube (left column), respectively wide (4 times its height, right column).
- The stack is placed in the middle of the building.

Each panel shows both the geometry of the simulation and the results in terms of concentrations. The wind blows from the left to the right. Results are shown for AERMOD, for standard OML and for MISKAM, with and without building. The full drawn curves refers to scenarios with a building, and the dotted curves to scenarios without. In addition to model results, measurements are displayed as the black curves.

The physical dimensions in the wind tunnel and on the graph's x-axis are in mm, but the results can be scaled. The building height is 150 mm, and the boundary layer in the wind tunnel has been found to be 700 mm. When results are scaled, all length scales are adjusted, whereas the wind speed remains the same.

It is a useful exercise to inspect plots like those of *Figure 1*. As noted, a much wider variety of scenarios is available for inspection in the report previously referred to. In *Figure 1*, it appears (top row) that for a relative stack height of 1 measured results are not very sensitive to the building width. The standard OML model, which uses a simple building downwash algorithm, does likewise not show any sensitivity to building width, whereas AERMOD/PRIME – in contrast to reality – shows a strong dependence with building width, and overpredicts by a factor of more than two close to the building. As a contrast, it is interesting to note that with a relative stack height of 1.5 (lower row in *Figure 1*), building width *does* have a substantial influence on results. Maximum ground-level concentration for the wide building is more than twice of that for the cube. However, in this case, AERMOD does *not* reflect this dependence, and neither does standard OML.

The entire series of plots reveal many discrepancies between observed concentration profiles versus those modelled by AERMOD and OML. A discrepancy, which is characteristic for many cases modelled with OML is that the model predicts the maximum concentration as close to the building as the model permits (e.g. the lower left panel in *Figure 1*), while the maximum in reality occurs further away. Although the location of the maximum is misrepresented, the size of the maximum is often in reasonable agreement with the observed maximum.

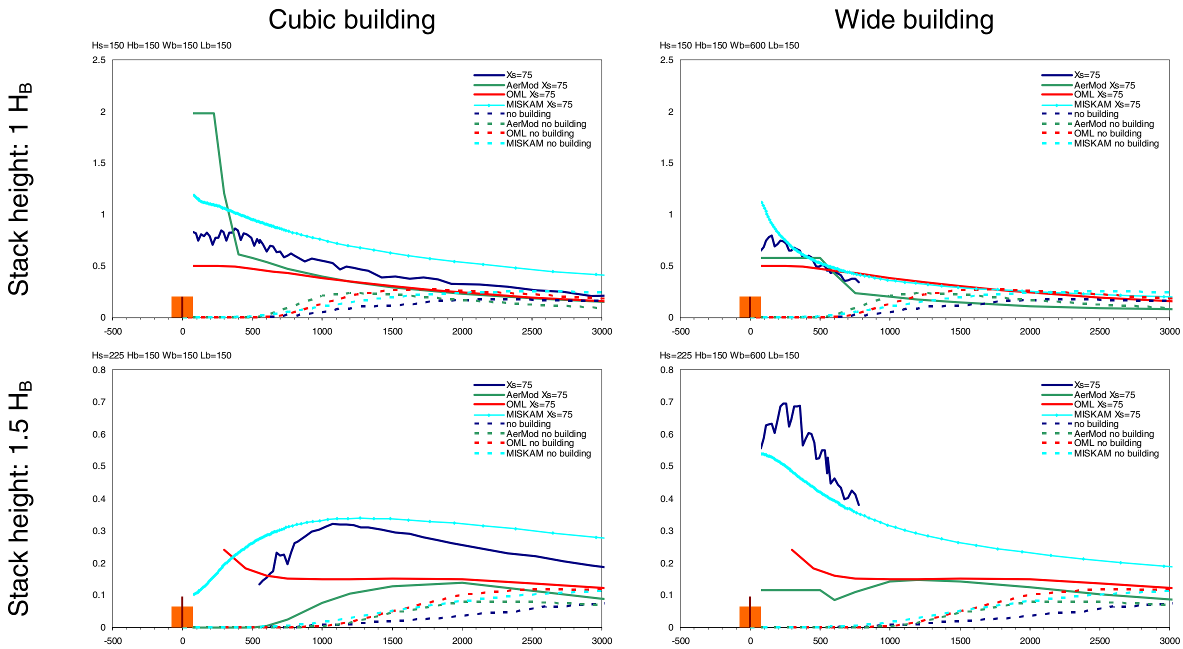

Figure 1 Along-wind concentration profiles for four scenarios, both with building (full drawn lines) and without building (dotted lines). As measured, and as modelled by AERMOD/PRIME, standard OML and MISKAM.

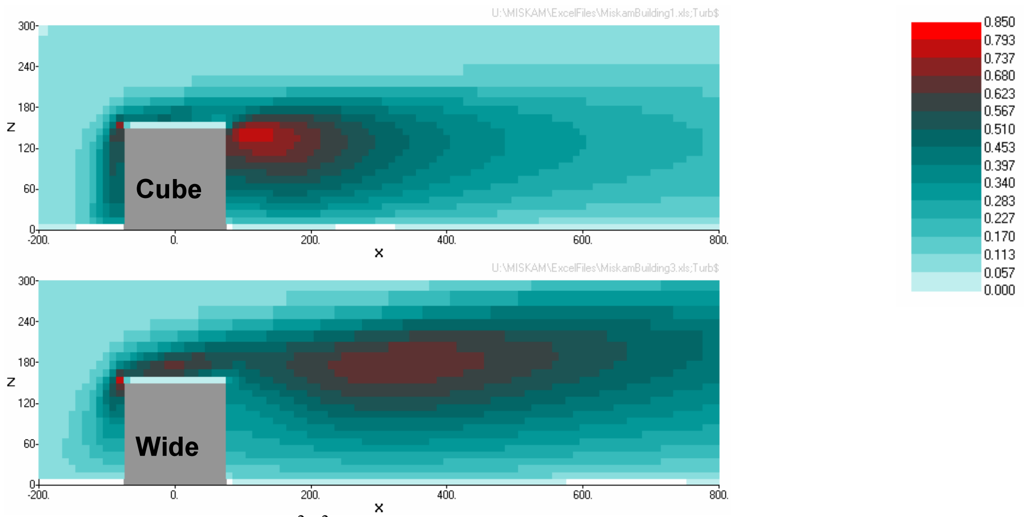

Figure 2 Turbulent kinetic energy (TKE, m^2/s^2), according to MISKAM in an x-z cross-section in the centre of the building. Top: the cube building; bottom: the very wide building.

The CFD model MISKAM has been used in an attempt to understand the different behaviour that building width has on dispersion from a stack with a relative height of 1, compared to an elevated stack. MISKAM runs were conducted for the four cases in *Figure 1*. MISKAM much more faithfully reproduces the concentration profiles than the simple models. The fact that MISKAM is a CFD model allows us to visualize the modelled distribution of the turbulent kinetic energy (TKE) in the x-z plane, as indicated in *Figure 2*.

It is interesting to compare the TKE pattern caused by the cube, respectively the wide building. A non-buoyant plume emitted at a height of 1.5 times the building height will experience very different levels of TKE, depending on whether it is released over a cube or over a wide building. If, on the other hand, the plume is released *at roof level*, it will be affected by high levels of TKE for both building shapes. This can qualitatively explain why concentration results for an elevated stack are much more sensitive to building width than results from a roof-top stack. Relatively simple models like AERMOD and OML do not account correctly for these effects.

One can gain insight into model behaviour by inspecting the more than hundred available plots like those of *Figure 1*. It is an impossible challenge to provide a synthesis of results in a way that retains *all* information from the individual graphs. Nevertheless, various types of syntheses can be produced that illustrate important features.

The original paper by Thompson (1993) presents contour plots of the so-called Building Amplification Factor, BAF. The BAF is formed by comparing two situations: a situation where a building is located near a stack, and a reference situation without a building. For both situations, the maximum ground-level concentration is determined. The ratio between these two concentrations is the BAF. The value of the BAF depends on the height and position of the stack relative to the building.

Thompson's studies of BAF allowed him to conclude that the Good Engineering Practice 2.5-times rule (according to which a stack height of 2.5 building heights is sufficient to make building effect negligible) is inadequate for wide buildings. Furthermore, the results indicated that even with a distance between stack and building of ten times building height, the buildings still has a significant effect on maximum concentrations.

We have chosen to present results for a somewhat similar parameter that carries information on model performance: We determine the maximum ground-level concentration (along the concentration profile), according to the model and according to measurements. The ratio of the modelled to the observed – one may call it the *Model Discrepancy Factor* (MDF) – is computed. A perfect model would have a MDF of 1 for every scenario. Note that a MDF of 1 certainly is no guarantee that the model is correct, as the *location* of the maximum might be misplaced. In *Figure 3* the performance of OML and AERMOD in terms of MDF is exposed.

Figure 3 contains a lot of information in a very condensed form. Each numbered label summarises information for an entire scenario. Pay attention to the fact that at *a given point in space* the degree of misprediction by a model may be more serious than the numbers in the figure indicate.

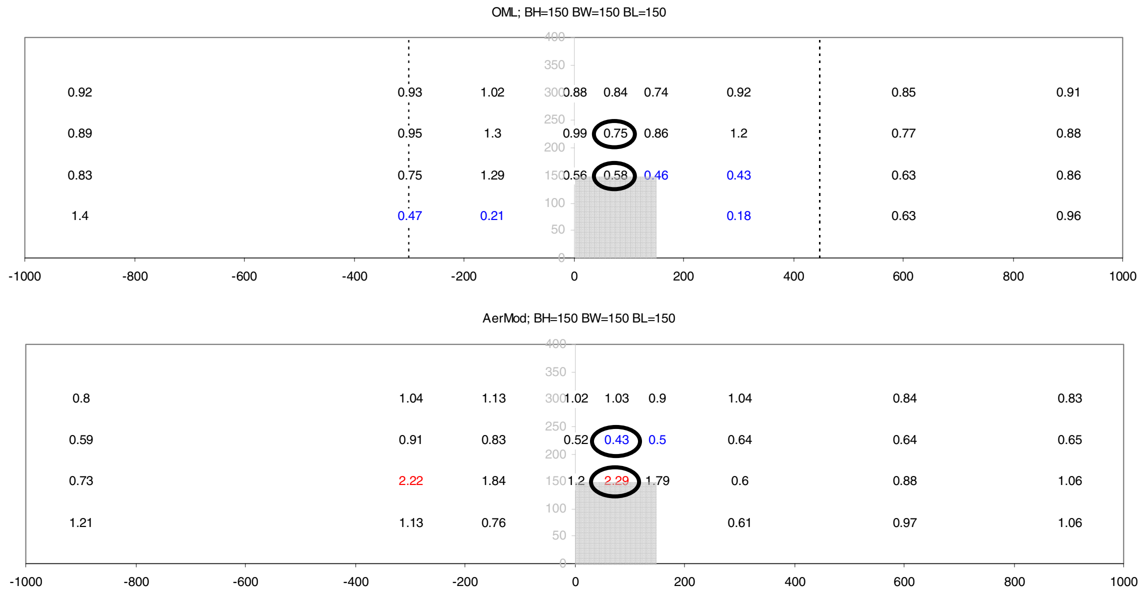

Figure 3 "Model Discrepancy Factor" for 33 scenarios with different combinations of stack height and stack location, all pertaining to the cube building. The upper plot refers to OML, the lower to AERMOD. The position of each label indicates the scenario. Results corresponding to *Figure 1* are encircled. E.g., the red label of 2.29 in the lower plot indicates the MDF for AERMOD for the scenario displayed in the upper left of *Figure 1*. Overpredictions by more than a factor of 2 are in red, underpredictions worse than 0.5 are in blue. For OML, the dotted lines indicate how far the building effect extends according to the current, simple algorithm.

5. CONCLUSION

Thompson's data set is very comprehensive, and deserves to be used much more than it has been in the past.

The concepts of BAF and MDF are useful for obtaining an overview of results, but looking at such factors alone is not sufficient to provide an adequate synthesis of results. One can learn by inspecting plots with results for individual scenarios, like *Figure 1*. The data have been organised in a spreadsheet with embedded graphs, so that it is easy to vary parameters and inspect concentration results for measurement and models. With a relative stack height of 1 measured results are not very sensitive to the building width, but with a relative stack height of 1.5, building width *does* have a substantial influence on results. Measured maximum ground-level concentration for the widest building is more than twice of that for the cube building. Such dependence is reflected in neither AERMOD/PRIME nor standard OML. For the limited number of cases where we have MISKAM runs, the discrepancies are much smaller. MISKAM is clearly superior to AERMOD/PRIME and OML.

On basis of the studies it was decided not to replace the OML building algorithm with the PRIME algorithm. It is an overall impression from the results that there is not much to be gained by directly replacing the building algorithm of the standard OML model with that of PRIME. The OML model has some weaknesses, but so does AERMOD/PRIME.

From a model user's point of view, the overall conclusion of the present study is that a user of either AERMOD or OML must accept rather large deviations between model predictions and observations for many situations. Predictions in the far field, away from the stack, are reasonable, but in the near field there can easily be overpredictions or underpredictions by a factor of 2 for both models. Such are the current limitations of the models. This claim presumably applies to many other simple models. If a modeller's purpose is an accurate prediction of concentrations close to a building, he can consider using a model of an entirely different type such as MISKAM. However, MISKAM is orders of magnitude more demanding in terms of required man-power, user skill and computer resources.

6. REFERENCES

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