Effects of Geometrical Simplification and Idealization on the Accuracy of Microscale Dispersion Modelling

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1. Introduction

Modelling turbulent flow and dispersion phenomena within the urban canopy layer requires to deal with one of the most complex meteorological and fluid mechanical environments. Pollutant dispersion and urban climate are determined by complicated physical, chemical and geometrical boundary conditions as they occur in built up city centres, industrial sites and living areas. Consequently, the measurement, modelling and prediction of urban type flow and dispersion phenomena requires significant simplification and abstraction of the real situation, no matter what kind of approach is being used.

In the case of field measurements idealisation and abstraction means placing a limited number of measurement devices at a few measurement points, in order to capture flow and dispersion processes representative for a whole street canyon, a city district or even an entire city. In most cases field measurements have to rely on the experience of the person planning the experiments and, if at all, only a small amount of information on the representativeness of the field measurements with respect to the complex urban environment is sampled (see Oke, 1999). Thus, it is almost impossible to quantify the reliability of field data with respect to the temporal and spatial variation of measured quantities in a complex urban area using the field data only.

Numerical modelling overcomes, in principle, some of the limitations field campaigns have regarding idealization and simplification because model results can be generated in a more or less dense grid covering at least a part of the urban area. On the other hand, numerical modelling requires drastic simplifications with respect to the physics behind urban type flow and transport phenomena. Geometrical discretisations and physical parameterisations are used when models are developed and the quality of discretisation and parameterisation largely effects the quality the model results can reach at all (see Schatzmann et.al. 1997). Due to limitations in computing power and computer memory, simplification and idealization leads to the common box-structured representation of the urban canopy and, at least for models resolving flow and dispersion problems within street canyons, the size of the modeled area is limited to a few hundred metres.

Just as for field measurements and numerical modelling, a certain level of abstraction is incorporated in any physical model tested in a boundary layer wind tunnel. Simplification is introduced into wind tunnel modelling, for instance, when a flow and dispersion experiment is limited to the conditions of neutral or near-neutral stratification. Depending on the expenditure of modelling, aerodynamic models of city districts or built up areas might show a wide variation of geometrical detail. The same holds true for the modelling of emission sources as well as the modelling of local phenomena like car induced turbulence. However, one of the special benefits of physical modelling is that flow and dispersion follow the same physical relationships as in the field as long as well known similarity criteria are met. In addition, most of the boundary conditions of wind tunnel experiment can be controlled at will and the boundary conditions can be kept constant over a long period of time. Since all boundary conditions can be measured with high temporal and spatial resolution, physical modelling can be used especially for the quantification of the effects of geometrical simplification on the results of microscale flow and dispersion modelling.

Based on the results of a number of systematic wind tunnel experiments, the effects of geometrical simplification on the results of point-wise flow and dispersion data will be illustrated. Uncertainties in model results due to spatial resolution limits will be visualised and discussed with respect to the overall accuracy of microscale dispersion modelling.

2. Experimental Setup

During the last five years, a number of research projects dealing with microscale flow and dispersion phenomena at 3 particular field monitoring stations has been carried out in the wind tunnel laboratory of the Meteorological Institute at Hamburg University. Within the scope of the projects the spatial and temporal representativeness of results from local field monitoring stations has been assessed based on systematic tests in a boundary layer wind tunnel. The field monitoring stations investigated so far represent, at least to some extend, different types of urban environments. The "Göttinger Straße" monitoring station (Hannover, Germany) might be called an almost ideal straight street canyon because it is surrounded with closed building walls (Liedtke et. al. 1998). The "Jagtvej" case (Kopenhagen, Denmark) is characterized by a slightly wider street canyon and a more 'open' arrangement of the surrounding buildings. In the most recent study, another street monitoring station in Hannover, at "Podbielsky Straße" was investigated. The "Podbielsky Straße" station is a rather short and narrow street canyon surrounded by strongly structured buildings and streets. In all three cases a detailed physical model of the area surrounding the field monitoring station was built at a model scale 1:200. In addition, each of the models was completed by an extended fetch for two representative wind directions. In order to visualize effects of strong geometrical abstraction for each of the test cases a box-structured representation of the field site, like it is used by most of the grid based numerical models, was built. Figure 2.1 shows pictures of the detailed and simplified physical models placed in the test section of the wind tunnel.

All experiments have been carried out in the multilayer wind tunnel of the Meteorological Institute. The facility, originally built for modelling stable thermal stratification and inversion layers, was chosen because it is providing a test section which is 2 m wide and 1 m high, enabling a large area to be modelled at a scale of 1:200. A conventional spires/floor roughness configuration was used for adapting the modelled boundary layer flow to near-neutral urban type conditions with a power law exponent of approximately 0.28 and a roughness length $z_0 \approx 1.2$m. All model tests have been carried out under identical boundary conditions in order to investigate the effects of different geometries without interference of changing wind flow boundary conditions. For flow measurements a 2D Laser Doppler Anemometer (LDA, DANTEC®) was used. For dispersion modelling, the models have been equipped with line sources emitting a constant amount of tracer (Ethane) at each point of the source (see Liedtke et. al. 1998). Concentration measurements were carried out by means of FID/FastFID systems providing even high resolution time series of concentration fluctuations up to 400 Hz. For controlling the experiment, automated data acquisition and online data reduction a custom-made PC-based measurement system was used, enabling extensive measurements to be carried out in an reasonable amount of time.

3. Basic Results

In a first step, the results acquired for a detailed physical model have been compared with data taken from the corresponding simplified model. As expected, distinct differences can be found at least for the cases were geometrical abstraction led to a coarse simplified model ("Göttinger Straße"). The differences between the detailed and simplified model are less for configurations where even the box-structured simplified model incorporates much detail and the urban area is characterized by a very dense grid of building but no absolute agreement of the results was found in any of the cases investigated.

In a second step, results acquired using the core of a detailed model have been compared to those taken from the same model with an extended built-up area. From the few comparisons it can be concluded that the fetch required for representative modelling of an urban type flow and dispersion problem varies with the type of the site investigated. In closed narrow street canyons the differences between the core model results and those taken from an extended model are small. For more open street canyons the effect of an enlarged model area might be visible even for a fetch length of several tens of building heights in front of the measurement point.

In another experiment the effect of an increased roughness of the building surfaces due to, e.g., balconies, ledges and oriels was investigated. A comparison of data taken with increased building surface roughness with those from the "smooth" aerodynamic rough model show only minor differences. Obviously the size of the additional roughness elements as well as their location on the building surfaces make them causing only minor effects on the overall street canyon dispersion. However, the significance of detailed modelling of surface structures might be bigger in cases were pollutant transport on building surfaces or the contamination of a building by pollutant transport trough facades is of interest.

4. Conclusions

Based on the results of systematic investigations in a boundary layer wind tunnel it was demonstrated that geometrical simplification and abstraction can have a significant effect on the results of local scale dispersion modelling. However, the comparison of model results taken from models with different complexity but otherwise identical boundary conditions clearly demonstrate that the significance of the effect of simplification depends on the complexity of the urban situation modelled.

Consequently, it can be concluded that a further improvement of the quality of numerical modelling might not be possible by just a further increase in the geometrical resolution or an extension of the area modelled. Major discrepancies found between the results of numerical modelling and field and laboratory measurements might still be caused by an improper physical representation of microscale flow phenomena in state of the art urban-type dispersion models.

It is intended to extend the systematic laboratory experiments towards the formulation of basic recommendations on how to define the required model areas as well as the required detail in physical and numerical modelling for urban-type flow and dispersion phenomena. In addition, the systematic wind tunnel tests will result in an improved knowledge on the spatial and temporal representativeness of local field measurements in urban areas.

5. References

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6. Acknowledgements

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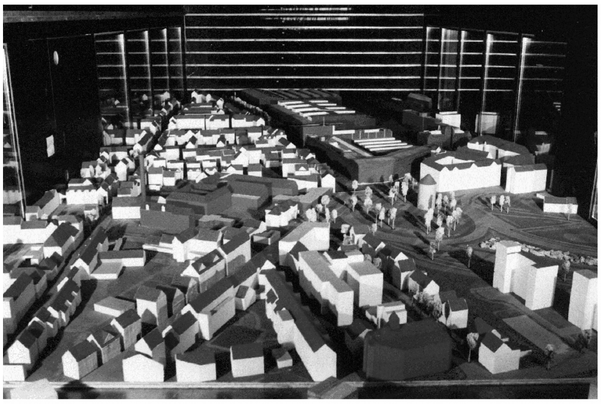
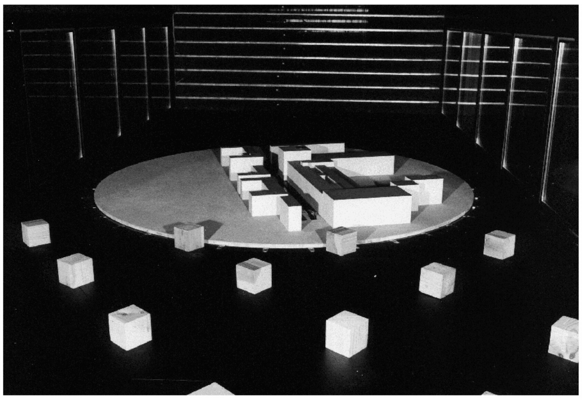
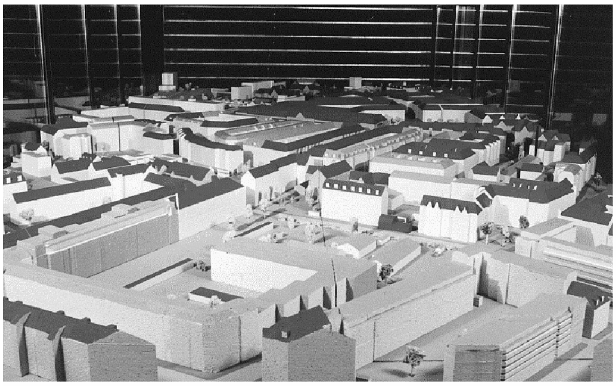


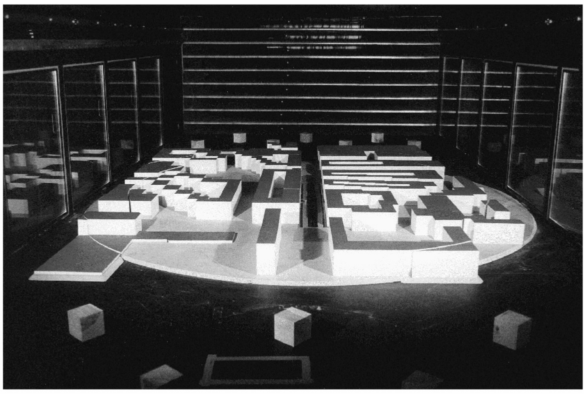
Göttinger Straße, Hannover (Germany)
detailed physical model



Göttinger Straße, Hannover (Germany)
simplified model

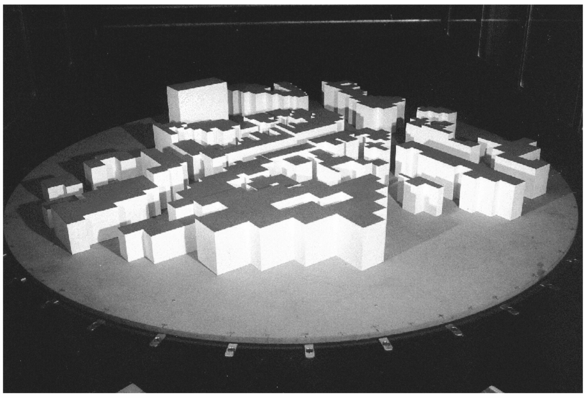


Jagtvej, Kopenhagen (Denmark)
detailed physical model



Jagtvej, Kopenhagen (Denmark)
simplified physical model

Podbielskystraße, Hannover (Germany)
detailed physical model



Podbielskystraße, Hannover (Germany)
simplified model

Figure 2.1: Detailed and simplified wind tunnel models set up in the test section of the multilayer wind tunnel of the Meteorological Institute at Hamburg University.