Meteorol Atmos Phys 87, 121–131 (2004)
DOI 10.1007/s00703-003-0065-4

Meteorology and Atmospheric Physics

Printed in Austria

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The influence of street architecture on flow and dispersion in street canyons

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With 6 Figures

Received August 20, 2003; accepted September 24, 2003
Published online: June 2, 2004 © Springer-Verlag 2004

Summary

The paper presents an overview of the influence of street architecture on the wind and turbulence patterns in street canyons and discusses the effects on local air quality. The findings of recent experimental and numerical studies are summarized and wind-tunnel data sets are presented that illustrate the flow-field variability. It is shown that small-scale features of the street architecture play an important role. The formation of a vortex inside the street canyon is affected by the roof configuration. In shorter street canyons, the flow component along the street becomes important for pollutant transport. These results are of importance for urban air quality modeling in particular when dealing with pollution problems caused by road traffic. Furthermore, the findings should be taken into account in fast response models that are used to assess critical areas in the case of accidental or non-accidental releases of hazardous material in urban areas.

1. Introduction

During the 20th century, an increase in urbanization has been observed worldwide. This trend can be expected to continue, and the environmental impact of urban areas is of growing concern. One of the major problems in urban areas is atmospheric pollution. Airborne pollutants are released by a variety of sources and differ in their physical and chemical nature. A comprehensive overview of the urban effects on air quality was recently presented by Britter and Hanna (2003). They discuss the different spatial scales that are of importance for particular pollution problems.

On the regional scale (up to 200 km in the horizontal direction) a large area can be affected by the so-called urban plume – a mixture of primary and secondary pollutants. Tropospheric ozone pollution is a good example for this category. The primary pollutants originate mainly in urban areas while the highest concentrations of ozone – a secondary pollutant that forms in the atmosphere due to photochemical reactions of the primary pollutants – typically occur downwind of urban areas. The transport and mixing of the urban plume is influenced by urban weather modifications. Typical examples for such modifications are urban heat-island effects, and horizontal and vertical flow deflections due to the increased drag in urban areas. When dealing with regional-scale pollution problems, air quality models consequently should account for chemical reactions in the atmosphere and reproduce the urban perturbations on the synoptic-scale weather patterns, but there is no need to resolve the complex flow patterns around individual buildings. However, the flow and turbulence characteristics inside the urban canopy – the region of the urban boundary layer in which the flow is affected by the local environment (building shapes and densities, type of vegetation etc.) – are key parameters when dealing with neighborhood or street-scale pollution problems. A good example of pollution problems of this category are emissions from road traffic. These emissions occur near the ground, and dispersion of the exhaust gases is highly affected by the complex flow phenomena inside the urban canopy. Other examples are the dispersion of hazardous material that can be accidentally released in industrial areas. Nowadays, also terrorist attacks with a release of chemical and biological agents are an important concern. In both cases, emergency response personnel must be able to make a fast and reliable prediction of the areas with critical dosages. Flow phenomena around buildings will significantly alter the plume drift and mixing, and must be taken into account in such predictions.

The flow and turbulence characteristics inside the urban canopy are highly variable and depend on the building architecture and arrangement in the local environment. It is therefore very difficult to parameterize urban-canopy flow. However, there have been attempts to define categories of typical urban building arrangements (see, e.g., Theurer, 1999) and to classify urban flow phenomena according to these building categories. Situations with long buildings flanking relatively narrow streets – so-called street canyon configurations- are often associated with elevated pollution levels and have therefore received special attention in recent studies. During the last decade, modeling of street canyon pollution was, e.g., the major topic of the European Research network TRAPOS (Berkowicz, 2001). Within this network, street-canyon flow and dispersion characteristics were primarily investigated with numerical models and in atmospheric boundary layer wind tunnels.

It is common for most of the numerical studies (a detailed review will be presented in the next section) that idealized building configurations are used, i.e. the buildings have rectangular shapes with flat roofs and are arranged in a regular manner. However, the wind-tunnel studies of Kastner-Klein and Plate (1999) and Rafailidis (1997) have shown that local features of the building architecture, like, e.g., pitched roofs, may significantly affect the dispersions characteristics in street canyons. The present paper focuses therefore on the influence of street architecture on air quality in street canyons. First, an overview of the different approaches that are used in street canyon studies will be presented. The present knowledge of typical flow phenomena and their relation to air quality in street canyons will be summarized in the following section. In the subsequent section, particular flow variations will be highlighted with the help of detailed wind-tunnel data sets. Finally, a comparison of wind-tunnel results from studies with idealized and realistic building configurations will be presented and the differences between the flow profiles will be analyzed.

2. Approaches used in street canyon studies

The morphology of urban landscapes is extremely variable and influenced by many factors. Geographical features and the time period of the major city development play important roles. Modern cities are often characterized by clusters of high rise buildings and wider streets, meanwhile older cities often have very narrow streets and densely-packed, few-storey high buildings. Figure 1 shows an example of a complex urban structure of the latter category. The noted differences in the urban morphology strongly impact the urban climate. Thus, if one is interested in predictions of the local air quality in a particular street or neighborhood of a city, the buildings structure in the area of interest must be resolved in the air quality model in detail. On the other hand, there are many applications when the resources for such detailed studies are not available. Accordingly, attempts have been made to define typical urban buildings structures based on their basic physical properties (built-up area relative to total area, ratio of street width to building height etc.), as it was done in Theurer (1999), and Ratti et al (2002), and to study the principal flow and dispersion characteristics for these different building categories. Also, it is still questionable if presently available numerical models are able to predict the complexity of urban flow and dispersion patterns accurately enough and evaluation strategies for urban air quality models have been widely discussed (Schatzmann and Leitl, 2002; Chang and Hanna,

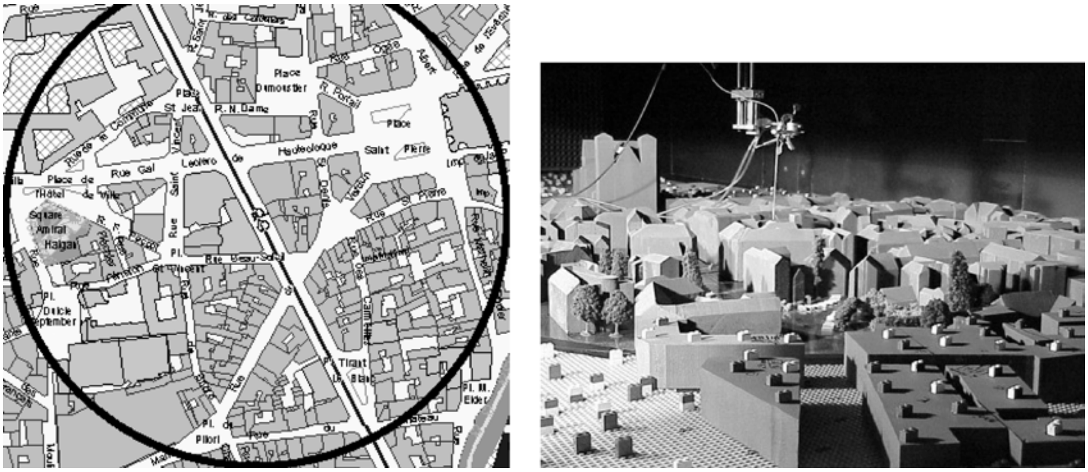

Fig. 1. Example of a complex urban street canyon situation: The left plot shows a street map with building contours for a central part of Nantes, France. The right picture shows a photo of a detailed wind-tunnel model in which the encircled area was reconstructed on the scale: 1:200 (Kastner-Klein and Rotach, 2004)

2004). Important steps of a model evaluation procedure are comparison studies between model calculations and experimental datasets, and also inter-comparisons of simulations with different models or by different users, see, e.g., Sahm et al (2002) and Ketzel et al (2002). Such studies are typically done for relatively simple building geometries, which can be clearly defined and easily implemented in numerical models. Accordingly, a large number of studies related to urban air quality focus on flow and dispersion in basic urban building configurations.

One urban building category that has been widely investigated during recent years is the street-canyon configuration. A review of modeling air quality in street canyons is given in Vardoulakis et al (2003). Generally, street canyon studies can be classified according to the degree of simplification used in modeling the urban building structure. Figure 2 presents an overview of different realizations of street-canyon configurations in air-quality studies:

(a) Isolated 2-D street canyon

This configuration defines the most basic approach to studying street canyon pollution. It has been used in wind-tunnel simulations (e.g., Kastner-Klein and Plate, 1999) and numerical modeling (e.g., Chan et al, 2001) mostly for model evaluation studies. This approach has the advantage that the boundary conditions can be well defined and parameters like the approaching flow direction or the canyon aspect ratio can be easily varied. On the other hand, it has the disadvantage of producing somewhat unrealistic urban flow and dispersion patterns. A typical urban street canyon does not have an undisturbed upwind fetch but, rather, a complicated urban surface, which seriously distorts the flow.

(b) Rows of 2-D street canyons

To address the problems with the single canyon, several studies with extended arrays of streets of the same geometry have been performed like, e.g., the ones of Meroney et al (1996) and Brown et al (2000). One of the questions of interest in these studies has been, at which row the flow starts to become self-similar and thereby, where street canyon pollution resembles an urban situation. Brown et al (2000) argue that this is the case after about the 6th row. Further upwind, the flow, turbulence, and dispersion conditions are to a large extent determined by the flow separation at the upwind edge of the first building.

(c) The cavity

As an intermediate case between street canyons of type a) and b) a cavity has been simulated, see, e.g. Kovar-Panskus et al (2002) and Sahm et al (2002). In this configuration there is no "first-building

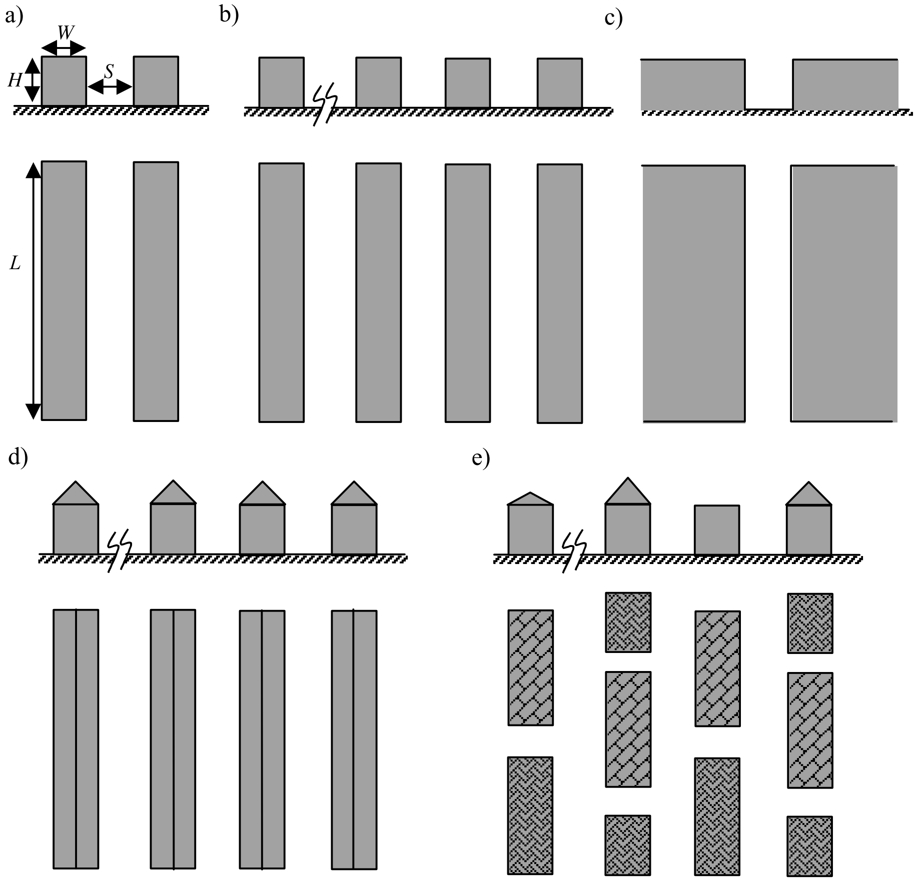

Fig. 2. Representation of idealized street canyon configurations with increasing complexity from (**a**)–(**e**), see text for details

effect'', but the upwind ''urban'' surface is not representative of a rough, irregular building pattern.

(d) Variable roof geometry

Urban buildings do not usually have a simple rectangular geometry and several studies were focused on the influence of different roof shapes on street canyon ventilation, see, e.g., Rafailidis (1997) and Kastner-Klein and Plate (1999). Such studies were done with a simple two building set-up, as well as with extended arrays of buildings of the same geometry. Buildings with pitched roofs as well step-down or step-up configurations (upwind building higher or lower than downwind building) were considered.

(e) Nonuniform geometry

The last category of idealized street canyon configurations is the one most closely resembling real urban configurations. Buildings of variable geometry are arranged on staggered or non-staggered arrays, which simulate the rough, irregular pattern of urban landscapes, see, e.g. Cheng and Castro (2002) and Chan et al (2003).

(f) Real urban surfaces

The most realistic modeling approach (not included in Fig. 2) for urban street canyons is certainly to reproduce the street geometry in as much detail as possible. This may be attempted in wind-tunnel simulations as well as in numerical experiments. A detailed physical model of an urban building structure that was used in the studies of Kastner-Klein and Rotach (2004) is shown in Fig. 1. Schatzmann and Leitl (2002) also discuss the value of such studies for model evaluation purposes.

3. Flow and dispersion phenomena in street canyons

Observations of flow recirculations inside long and narrow streets were already reported by Albrecht (1933). Later, the studies of Georgii et al (1967), and DePaul and Sheih (1986) confirmed that for wind directions approximately perpendicular to the buildings, vortices develop that are characterized by significant vertical velocities and reverse flow at street level. Among others, Louka et al (2000), and Caton et al (2003) confirmed these findings, but they also identified that street canyon vortices are rather unsteady and discussed that the mean and turbulent exchange at the canyon top can be best described with mixing layer concepts. The full-scale studies of Rotach (1993a, b and 1995), Louka et al (2002), and Vachon et al (1999; 2002) delivered also insights in the turbulence characteristics inside street canyons for different thermal regimes and variable traffic conditions.

As mentioned earlier, the aspect ratio S/H (see Fig. 2a for definition of variables) is usually considered as main criteria for the formation of a canyon vortex, and Oke (1988) distinguished between three different characteristic flow regimes depending on the value of S/H. The flow patterns around widely spaced buildings ($S/H \gtrsim 3$) are similar to those around isolated buildings (isolated roughness flow). For $1.5 \gtrsim S/H \gtrsim 3$ the wakes and front recirculation zones of the buildings interact but do not overlap (wake-interference flow). For $S/H \gtrsim 1.5$ the transition from the wake-interference to the skimming flow regime takes place. The main flow starts to skim over the buildings tops (skimming flow regime) and the formation of a canyon vortex becomes apparent. Such situations are typically associated with adverse air quality since the streets are only poorly ventilated. Accordingly, a number of studies focused on identifying the parameters governing the transition to skimming flow regimes.

Within the European Research network TRAPOS (Berkowicz, 2001) wind-tunnel experiments for two-dimensional cavities (type c) with five different aspect ratios within the range $0.3 < S/H < 2$ have been performed at the University of Surrey, United Kingdom. The aim was to investigate both the transformation from the wake interference to the skimming flow regimes and the influence of the aspect ratio on the vortex dynamics within the cavity. Simultaneously, numerical simulations of these configurations have been carried out with the $k-\varepsilon$ closure model CHENSI described in Sini et al (1996). The numerical calculations and experimental results have both shown that the number of recirculation zones inside the cavity and their positions vary with the aspect ratio. While canyons with a larger aspect ratio exhibit only one (primary) vortex with possibly a weak counter-rotating vortex near the bottom, narrower canyons can give rise to the formation of a multiple vortex structure. It may be ascertained from these data that the transition between wake interference and skimming flow regimes occurs for an aspect ratio $S/H > 2$. Moreover, the presence of weak vortices in the lower levels of the canyon creates poor conditions for the ventilation of traffic pollutants from the street.

Hunter et al (1990/91) and Johnson and Hunter (1995) also used a $k-\varepsilon$-turbulence closure model to investigate the influence of building geometry on flow and concentration fields in isolated 2-D street canyons (type a). They found an influence of the ratio building length to canyon height, L/H, on the vortex dynamics. In similar studies, Chan et al (2001; 2003) investigated the variation of street-canyon flow and pollution patterns with changes in the building geometry. A simple type (a) set-up was used in the first study while more realistic urban configurations of type (e) were simulated numerically with $k-\varepsilon$ turbulence closure in the second study. The objective was to find strategic guidelines for canyon geometry that will result in sustainable air quality. Chan et al observed that not only the S/H- and L/H ratios, but also the relative height of the buildings flanking the canyon have a noticeable influence on street-level pollution. They concluded that non-uniform roof heights provide better ventilation of the canyon. Kim and Baik (2003) in another study with a two-dimensional numerical model found that the in-canyon vortex and street canyon ventilation strengthen with increasing inflow turbulence intensities.

Assimakopoulos et al (2003) simulated extended arrays of type (b) canyons with the $k-\varepsilon$ closure-based model MIMO (Ehrhardt et al, 2000) using geometry and inflow data from wind-tunnel experiments performed by Rafailidis (1997) at the University of Hamburg, Germany. It was found that the pollution levels inside the canyon of interest increase in the case when the upwind building is higher than the downwind building (step-down notch), while the canyon is often better ventilated when the downwind building is higher than the upwind building (step-up notch). In the latter case, a single vortex is formed with a high-pressure area developed at the top corner of the roof level of the windward building. Maximum pollutant concentrations are observed on the leeward wall but the street ventilation is enhanced compared to the reference case. In the case of a step-down notch, a double vortex system appears with a primary vortex covering the upper part of the cavity, and to some extent the roof of the windward building. A secondary counter-rotating vortex is formed at the corner of the windward building. This complicated vortex system leads to maximum concentrations on the windward wall and to a trapping of pollutants.

The aforementioned studies all highlight the influence of canyon geometry on the street level pollution. The roof geometry appears to have a strong influence on the vortex dynamics and therefore also on the canyon ventilation mechanism. This finding is further supported by wind-tunnel results of Rafailidis (1997), and Kastner-Klein and Plate (1999). Rafailidis (1997) used buildings with pitched roofs in his type (d) setup and observed a substantial influence on the turbulence characteristics within and above the street canyon. Kastner-Klein and Plate (1999) investigated the influence of different roof shapes on the pollutant concentrations at the building walls of an isolated street canyon. The location and magnitude of the maximum street-level pollution strongly varied and they concluded that the roof geometry must significantly influence the vortex formation in the canyon. In order to study the influence of roof geometry on the vortex dynamics more carefully velocity measurements with Laser-Doppler Anemometry (LDA) were performed at the University of Karlsuhe, Germany. The results from these measurements will be discussed in detail in the following sections.

Furthermore, a comparison of flow data from three different wind-tunnel studies will be presented. This comparison will suggest answers to the questions (i) how strong is the influence of the particular wind tunnel setup on the observed characteristics of flow in street canyons, and (ii) to what extent can the flow characteristics be parameterized?

4. Experimental setup

The experiments have been performed in the atmospheric boundary layer wind tunnel of the University of Karlsruhe (UKA), Germany. A description of this facility and the characteristics of the neutrally stratified boundary-layer reproduced in the wind tunnel are given in Kastner-Klein (1999). Details about the UKA street-canyon studies are also presented in Kastner-Klein and Plate (1999) and Kastner-Klein et al (2001). The boundary-layer development is achieved with the aid of vortex generators installed at the entrance of the test section and by means of the roughness elements mounted on the wind tunnel floor. The typical boundary-layer depth in the vicinity of the street canyon location is of the order of 0.50 m. In the present study, isolated street canyons consisting of two bar-type buildings were investigated. The base height of the buildings forming the canyon has been 0.12 m, their length has been either 0.60 m, 1.20 m, or 1.80 m, and the distance between the buildings has been chosen to be 0.12 m. This corresponds to the aspect ratio $S/H = 1$ and to the length-to-height ratios $L/H =$ 5, 10, and 15. In the case of the buildings with pitched roofs triangular caps were added to the building base so that the level of the ridge was 0.16 m. The approaching flow has been directed perpendicular to the axis of the street, and the x-axis has been oriented along the direction of external wind. The reference velocity u_0 measured at the level $z_{ref} = 4H = 0.48$ m was equal to 7 ms^{-1}.

The mean flow and turbulence measurements in the wind tunnel were conducted with a laser Doppler anemometer in the central vertical plane of the canyon and in a horizontal plane at $z = 0.25H = 0.03$ m. In the latter case, only the horizontal velocity components (u, the along-wind velocity component and v, the lateral velocity component) were measured. In the central vertical plane all three velocity components were measured for most of the sampling locations inside the canyon and above it. However, due to technical constraints w, the z-component of velocity, could not be registered at all locations. From the obtained time series, mean flow parameters and one-point, second-order turbulence statistics have been derived.

5. Influence of building and roof geometry on the mean and turbulent velocity fields

A comparison of the flow patterns in the central vertical plane for the three different L/H ratios and three different roof configurations is shown

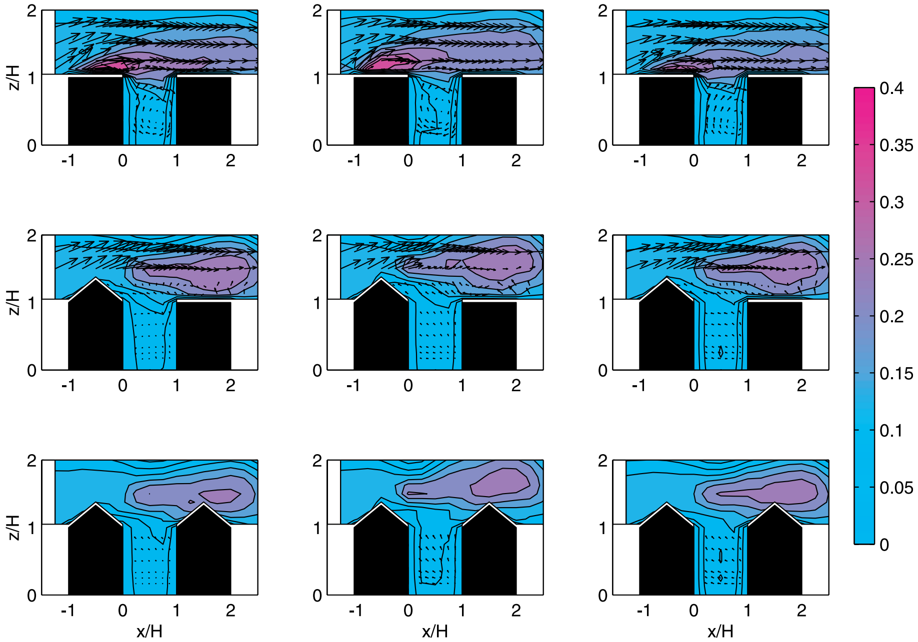

Fig. 3. Velocity in the central vertical plane of isolated street canyons with $L/H =$ 15 (left plots), 10 (middle plots) and 5 (right plots) for three different roof configurations. The mean velocity field is shown by vectors, the colors refer to σ_u/u_0

in Fig. 3. The mean velocity field is presented in form of velocity vectors whose length is proportional to the magnitude of the velocity. The isolines and color scale deliver information about the turbulence characteristics whereby the normalized variance σ_u/u_0 of the u-velocity component has been exemplarily chosen. The patterns for the variances of the v-, w-velocity components look similar and show the same tendencies. The positions of the velocity vectors indicate the sampling locations. For the situations with pitched roofs technical constraints impeded measuring the vertical velocity component over the whole grid. However, data for the u-velocity component, which are the basis for the isolines, are available on a dense grid inside the canyon and above roof level for all nine configurations.

For all cases studied with flat roofs, a flow separation can be noted at the upwind edge of the upwind building and a vortex forms within the canyon. Above roof level, a shear zone with increased turbulent velocities develops whereby the highest turbulence levels are observed above the roof of the upwind building. The extent of the shear zone, the magnitude of the increased turbulence levels, and the location of the vortex centre inside the canyon are influenced by the L/H ratio. With decreasing canyon length, the vortex centre is shifted closer to the downwind wall and the shear zone becomes less pronounced. Significant changes are observed for the situations with pitched roofs. For all cases studied with pitched roofs, the typical street-canyon vortex does not develop. Instead, a recirculation zone forms at the upwind building ridge and spans across the downwind building. At the canyon top, low wind velocities and reverse flow are observed, which hampers formation of a street-canyon vortex. As a consequence, the flow becomes almost stagnant inside the canyon. This pattern explains the increased pollution levels that were observed by Kastner-Klein and Plate (1999) for configurations with pitched roofs at the upwind buildings.

The velocity fields observed in a horizontal plane at $z = 0.25H = 0.03$ m (Fig. 4) further illustrate the significant variation of the flow pattern for situations with pitched roofs. For the situation with flat roofs and $L/H = 10$ (top plot), along-canyon velocity components are pronounced near the lateral building edges, but the flow is quasi two-dimensional close to the canyon centre. For both cases with pitched roofs (buildings with pitched roofs are shown in grey in Fig. 4) along-canyon velocity components are dominant over the whole span of the canyon. Such conditions can result in critical pollution levels if emissions from neighbor streets are transported into the canyons. Pollutants can then accumulate in the central region of the canyon where vertical mixing and thus canyon ventilation are rather poor (see Fig. 3). In the case of flat roofs, the extent of the lateral recirculation zone is about 2–3 H. Accordingly, a distinct area with quasi two-

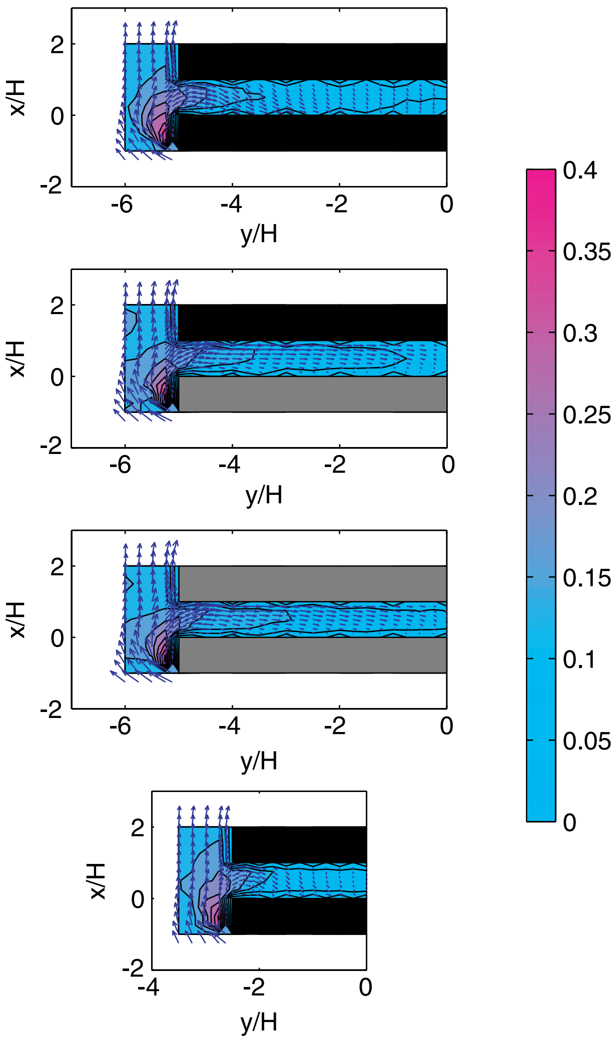

Fig. 4. Velocity in a horizontal plane at $z/H = 0.25$ of isolated street canyons with $L/H = 10$ and 5 for different roof configurations (due to symmetry only one half of the canyon is shown, $y/H = 0$ corresponds to the canyon centre). Buildings with flat roofs are plotted in black; buildings with pitched roofs are plotted in grey. The mean velocity field is shown by vectors, the colors refer to σ_u/u_0

dimensional flow does not exist in the case of the shortest canyon with $L/H = 5$ (lowest plot). The lateral recirculation zones converge in the canyon centre which causes stronger vertical motions for this configuration (see Fig. 3). This enhanced vertical transport promotes ventilation of the canyon and explains the lower pollution levels observed by Kastner-Klein and Plate (1999) for shorter canyons.

6. Comparison of street-canyon studies

The results presented in the previous section highlight the significant influence of building geometry on flow patterns in street canyons. On the other hand, these results were obtained for type (a) street canyon configurations, which are not a very realistic analogue for urban landscapes. In order to study the influence of the particular setup in the wind tunnel, the data have therefore been compared with results obtained in other wind-tunnel studies. The studies chosen for comparison and the corresponding references are presented in Table 1. For all experiments, mean values and turbulent statistics of all three velocity components were derived from high-resolution flow measurements. We discuss the spatial variability of the flow and turbulence fields inside and above the canyons, and the influence of urban canopy irregularities on the properties of spatially averaged flow profiles.

In addition to the isolated street-canyon study (IC-UKA) described in the previous section, data from wind-tunnel flow measurements performed in the wind tunnel of the U.S. EPA fluid modeling facility for a type (b) array of street canyons have been analyzed (IC-EPA). The aspect ratios S/H of the IC-UKA and IC-EPA idealized canyons (IC) were equal to one. The approach flow was perpendicular to the axis of the canyon and mean and turbulent velocities were measured in its central plane ($y = 0$ cm). For the RC-UKA study (Real Canyon), a detailed model of the central part of Nantes, France was constructed. Vertical velocity profiles were measured at several positions inside the model. The profile locations were chosen to trace the horizontal variability of the flow inside and above a street canyon (Rue de Strasbourg) oriented perpendicular to the wind direction. The results are discussed in detail in Kastner-Klein and Rotach (2004).

A comparison of IC-UKA and IC-EPA mean velocity and turbulence kinetic energy (TKE) profiles is presented in Fig. 5. As a velocity scale, the value $u(H)_{upw}$ at the level of the building height in the undisturbed approach flow is used. The IC-UKA results agree well with the data for the first canyon of the IC-EPA array. In both cases, the flow separation at the upwind building edge results in strong mean velocity gradients and high TKE values in a shear region above the roofs, where the largest differences are observed between velocity fields for the cases of the first and sixth IC-EPA canyons. The velo-

Table 1. Description of wind-tunnel studies employed in the presented comparison

Study	Building configuration	Measurement technique	Wind tunnel	References
IC-UKA	one idealized street canyon in non-urban terrain (type a), flat or slanted roofs ($L/H = 10$)	Laser Doppler anemometer	Neutral boundary layer wind tunnel, University of Karlsruhe, Germany	Kastner-Klein (1999)
RC-UKA	detailed model of an inner-city area in Nantes, France (type f)	Laser Doppler anemometer		Kastner-Klein and Rotach (2004)
IC-EPA	array of six idealized street canyons (type b), flat roofs	Pulsed wire anemometer	Wind tunnel of the U.S. EPA Fluid Modeling Facility	Brown et al (2000)

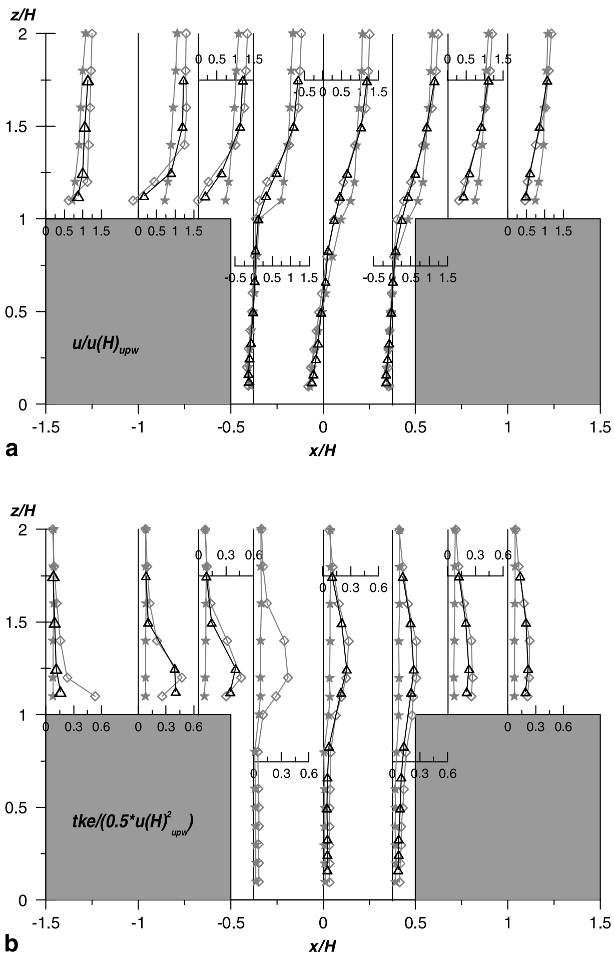

Fig. 5. Profiles of the u-velocity component (**a**) and TKE (**b**) in the central vertical plane of idealized street canyons. Triangles: IC-UKA, $L = 120$ cm. Diamonds: IC-EPA, first canyon. Stars: IC-EPA, sixth canyon

city field in the latter case corresponds to the skimming-flow type adjusted to the underlying surface. At roof level, the mean flow velocity increases rapidly to the boundary layer value. The TKE values in this case are small and do not significantly vary with height.

Spatially averaged profiles of the mean velocity and turbulence kinetic energy are presented in Fig. 6. The results of the RC-UKA study demonstrate that flow characteristics above a realistic irregular urban canopy are generally similar to the ones observed in the case of idealized regular building arrays. However, building pattern irregularities lead to more pronounced TKE maxima in the shear region above the roof level of the RC-UKA model compared with the related TKE value in the case of the sixth IC-EPA canyon. Furthermore, for RC-UKA the vortex formation inside the canyon is less pronounced, which can be explained by lateral flow components that become significant near intersections (not shown). Above roof level, a larger velocity deficit can be attributed to increased friction due to the nonuniform roof geometries in the case of the real urban landscape.

The mean flow and turbulence profiles at different locations within the RC-UKA model exhibit a fairly large variability. Kastner-Klein and Rotach (2004) discuss concepts to parameterize such complex flow profiles. They found that the mean flow above the canopy layer can be fairly well described by a logarithmic profile and that a local scaling approach allows approximating some features of the flow profiles within the canopy. However, such approach fails to reproduce important features of the skimming flow regime (like, e.g., the reverse flow in the lower part of the canyon) and the flow variability within the urban canopy can only be simulated if a detailed model of the building structure is used.

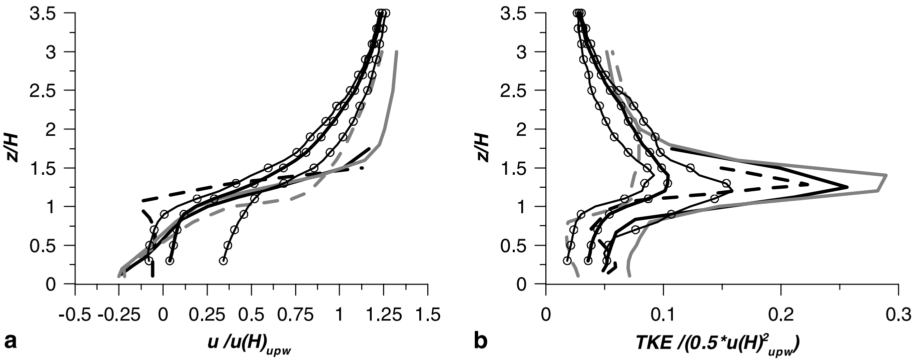

Fig. 6. Averaged profiles of the *u*-velocity component (**a**) and turbulence kinetic energy (**b**). Black lines: IC-UKA, solid for flat roofs and dashed for slanted upwind roof. Gray lines: IC-EPA, solid for first canyon and dashed for sixth canyon. Circles: RC-UKA (thick line – mean; thin lines – lowest/highest values)

7. Conclusions

We have found good agreement between the flow characteristics inside and above idealized street canyons of similar geometry studied in the two different tunnels. A vortex-type motion and associated reverse flow in the lower part of the canyon have been observed in isolated as well as in urban-type idealized canyons with flat roofs. In canyons formed by pitched-roof buildings, an in-canyon vortex does not develop and the vertical mixing between the canyon and the flow above is much weaker. However, vortex-type flow has also been observed inside a street canyon within a detailed model of a real urban canopy cluster although less pronounced than in the case of idealized buildings with flat roofs. Maxima in the TKE profiles above the building roofs have been associated with situations in which the canyon is close to a change in the underlying surface structure. The largest energy maxima have been found above isolated two-dimensional canyons.

In summary, the results from several recent experimental and numerical studies have shown that flow modifications inside street canyons that can be attributed to variations in roof geometry are not negligible. They impact the in-canyon vortex formation and dynamics as much as the aspect ratio value does. It became also clear that the upwind urban landscape determines to a certain extent the flow and turbulence structure and, hence, the pollutant concentration distribution in a given street canyon. Recent studies, in particular the ones performed in the framework of the research network TRAPOS, have substantially advanced the understanding of the influence of street architecture on pollutant dispersion within urban street canyons. Real-array wind tunnel or numerical studies, in which the details of the street canyon as well as its surroundings are modeled, seem to be necessary in order to obtain realistic results and in order to improve parameterizations of urban-type flows.

Acknowledgements

The study was supported by the European Commission and the Swiss Ministry of Education and Science (grant 97.0136) within the TMR-project TRAPOS. Special thanks go to Harald Deutsch, Armin Reinsch, and Jose Ribeiro, who were responsible for planning and conducting the wind-tunnel experiments at the Institute of Hydromechanics at the University of Karlsruhe, Germany.

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