Description of wind – tunnel studies on flow field and dispersion characteristics in street canyons at the University of Karlsruhe

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1. Experimental setup

The measurements were done in the neutrally stratified atmospheric boundary-layer wind tunnel at the Institute of Hydromechanics, University of Karlsruhe (details see in Kastner-Klein, 1999, Kastner-Klein and Plate, 1999). The test section is 2 m wide and 1 m high. The boundary layer characteristics will be described below. A general impression of the experimental setup gives the photo shown in Fig. 1. The buildings are placed at the test section on the wind tunnel floor. Usually only two building rows were mounted, surrounded by homogeneously distributed roughness elements. In the particular case the wind direction was perpendicular to the street and the buildings were 120 cm long.

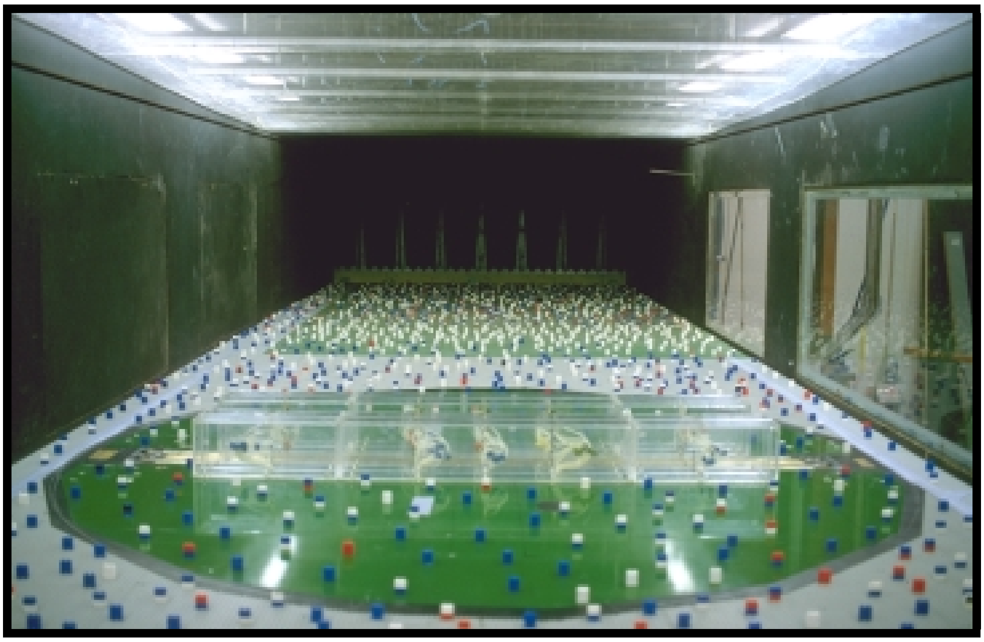


Fig. 1: Wind tunnel model of an idealised street canyon mounted in the atmospheric boundary-layer wind tunnel at the University of Karlsruhe.

More details concerning the building configurations studied, are given in the sketch shown in Fig. 2.

The following geometrical parameters were not varied and had the fixed values:

Width of additional buildings: $B4 = B3 = 12$ cm

Width of the streets: $D1 = D2 = 12$ cm

Height of buildings (flat roof cases): $H = 12$ cm

(the actual height varied during the roof geometry study, details are given in Appendix 1)

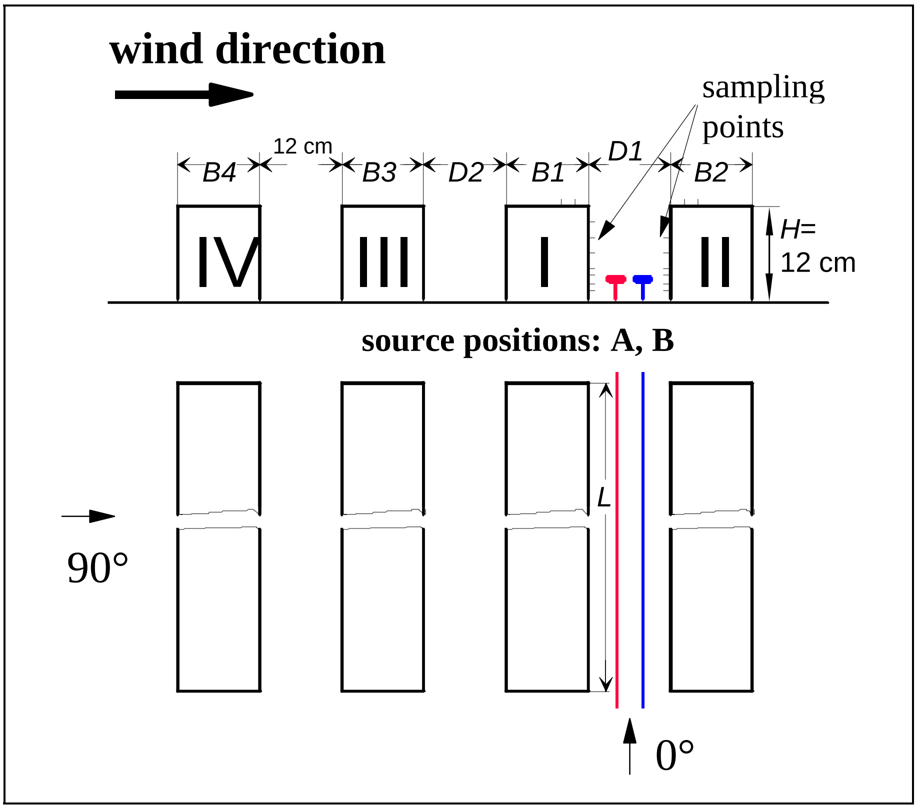


Fig. 2: Sketch of the experimental set-up for the wind tunnel studies with idealised street canyons in the atmospheric boundary-layer wind tunnel at the University of Karlsruhe.

All the information corresponding to the situations studied with respect to dispersion characteristics are listed in Tab. 1. The situations with 180 cm long buildings were done with additional plates at the lateral canyon edges to guarantee twodimensional dispersion characteristics inside the street. For all cases vertical concentration profiles along the walls and roofs (two points) of building I and II were measured. Usually three profiles were taken at each building at the positions:

$y = 0$ cm (central profile at the symmetry plane of the buildings)

$y = \pm(L/2 - 15\text{ cm})$ (profiles near the lateral building edges with a distance of 15 cm from the edges)

The sampling points had a distance of 7 mm from the building walls. Emissions from the two line sources A and B were studied independently. The distance between the wall of building I (in future called leeward building wall) and source A was 35 mm, the distance of source B was 85 mm. The length of the line sources was $L_q = 142\,\text{cm}$. A mixture of air and the tracer gas SF_6 was released near the ground from thin tubes (diameter $d = 0.5$ mm, length $l = 25$ mm, distance between the tubes $a = 5$ mm). Ten millimetre wide and two millimetre thick metal stripes were placed above the holes in the distance $\Delta z = 2\,\text{mm}$ to avoid a formation of separate jets with a significant vertical momentum. Test measurements proofed the lateral homogeneity of the source and the Reynolds - number independence of the concentration results (Kastner-Klein, 1999). The measurement results are available in the form of normalized concentrations $c^* = \dfrac{c \cdot u_0 \cdot H}{Q / L_q}$.

Measurements of flow field characteristics with a two-component laser velocimetry system were taken for the situations listed in Tab. 2. The location of sampling points, the type of measurements and the available data are documented also in Tab. 2.

2. Approach flow conditions

In the wind tunnel a boundary layer flow is generated by the means of vortex generators at the entrance and roughness elements on the floor (see Fig. 1). The mean and turbulent characteristics of this boundary layer can be summarized as:

The mean velocity profile of the boundary layer in the wind tunnel (see Fig. 3) can be described by a power law with an exponent $\alpha = 0.23$:

$$\frac{u}{u_{ref}} = \left(\frac{z - d_0}{z_{ref} - d_0} \right)^{0.23},$$

The displacement height can be given as: $d_0 = 2\,\text{mm}$.

In the lower part of the boundary layer ($20\,\text{mm} \le z \le 100\,\text{mm}$) the data correspond well with a logarithmic profile

$$\frac{u}{u_s} = \frac{1}{\kappa} \ln\left(\frac{z}{z_0}\right),$$

with

shear stress velocity $u_* = 0.055 \cdot u_0$

and

roughness length $z_0 = 0.8\,\text{mm}$.

(u_0 represents the velocity in the boundary – layer height $\delta \approx 480\,\text{mm}$).

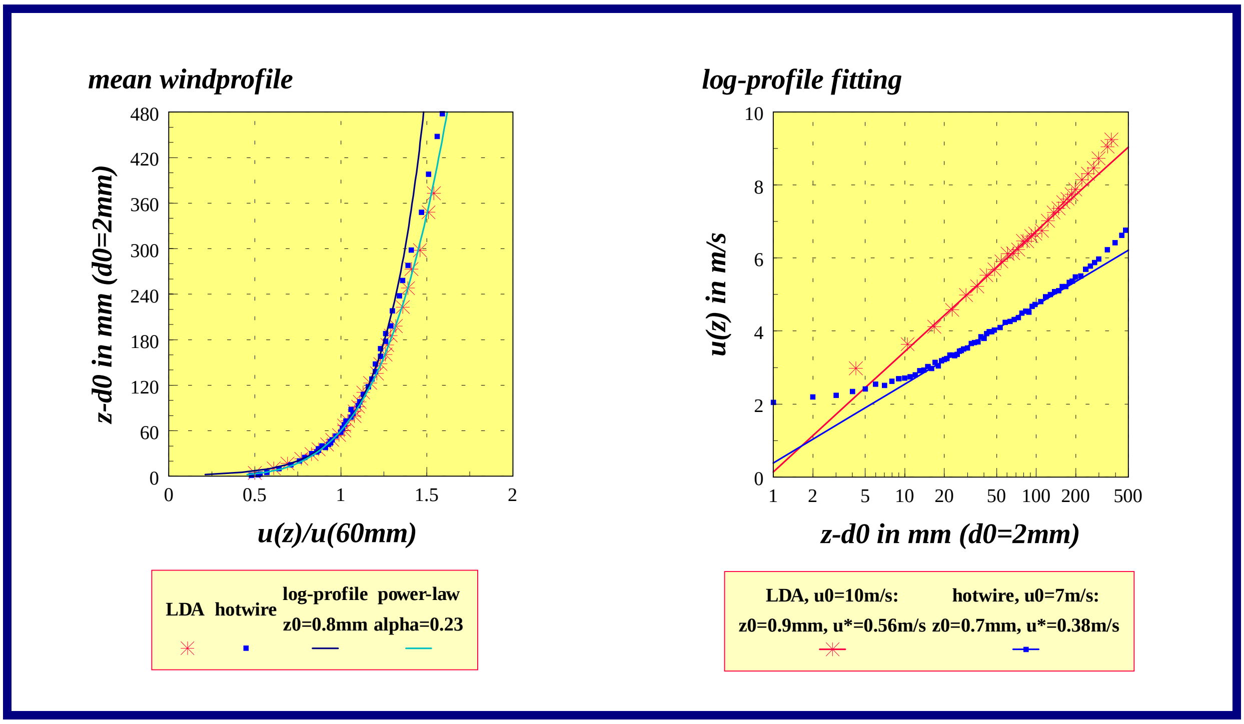


Fig. 3: Mean velocity profile of the boundary layer in the wind tunnel at the University of Karlsruhe.

Measurements were taken with the Laser-Doppler velocimetry technique (LDV or LDA) as well as with a single hotwire. From the LDV measurements the mean and turbulent velocities of all three components and also the correlations $\overline{u'w'}$, $\overline{u'v'}$ are known. The integral length scale L_{ux} was calculated by numerical integration of the autocorrelation function $R_{uu}(\tau)$ up to the first zero value (Graphs of all characteristics are shown in Appendix 6). Spectra of the *u*-component were calculated from time series measured with a single hotwire and a sampling frequency of 200Hz in three different heights (see Appendix 7). All data are available on request in digital format (gsdat.xls, spectra.xls).

Comment:

According to the flow characteristics the wind-tunnel boundary layer corresponds to the atmospheric boundary layer scaled by a model scale $M = 1/500$. A realistic value for the geometrical scale of the buildings lays in the range $M_g \approx 1/150 - 1/200$. Comparison of the wind-tunnel boundary layer with a full-scale boundary layer using the model scale $M_g = 1/150$ gives a acceptable agreement for a boundary layer characterized by the parameter $z_0 = 0.1\,\mathrm{m}$ and $\alpha = 0.18$ (Kastner-Klein, 1999).

3. Results

Files with the concentration and flow field data will be distributed for free on request for specified situations according to Tab. 1 and 2.

Information concerning the concentration data:

The z – coordinate indicated in the files represents a coordinate following the building contour. The points with z < 120 mm were located at the wall and the z – value represents the height. The points with z > 120 mm were located on the roofs and for this points the z – value indicates the distance from the canyon wall $d' = z - 120\,\mathrm{mm}$.

During the dispersion studies the 2 roof top sampling points were not working for all situations. In this cases the value 0 is listed in the data files.

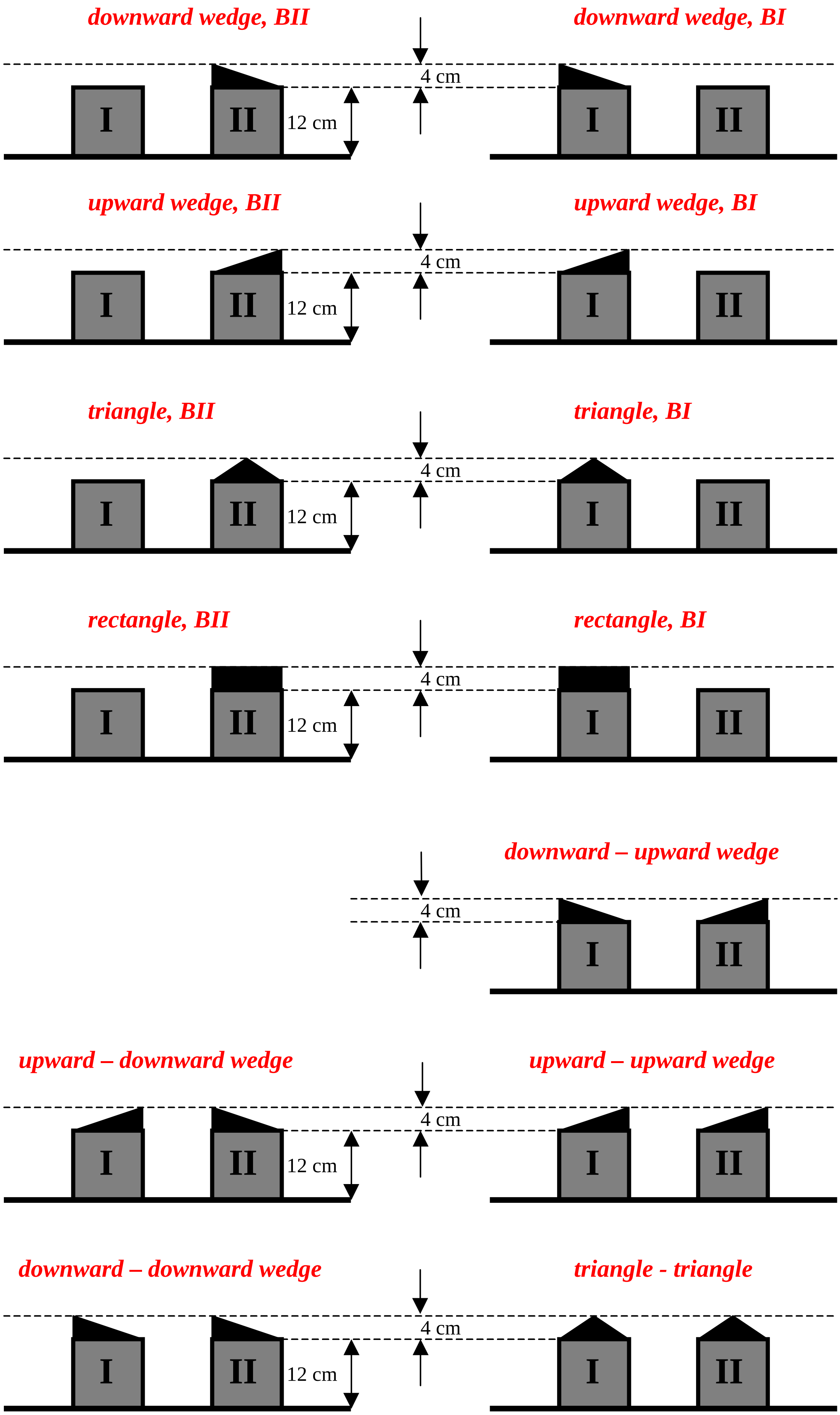
Please note that the length of the source was $L_q = 142\,\mathrm{cm}$ during all experiments. This is the reason why the concentration is very low at the profiles $y = \pm(L/2 - 15\,\mathrm{cm})$ for the situations with 180 cm long buildings. Measurements with additional profiles closer to the centre proofed that in a region $y = \pm 0.3 \cdot L$ two dimensional dispersion characteristics were realized for cases with 180 cm long buildings.

References:

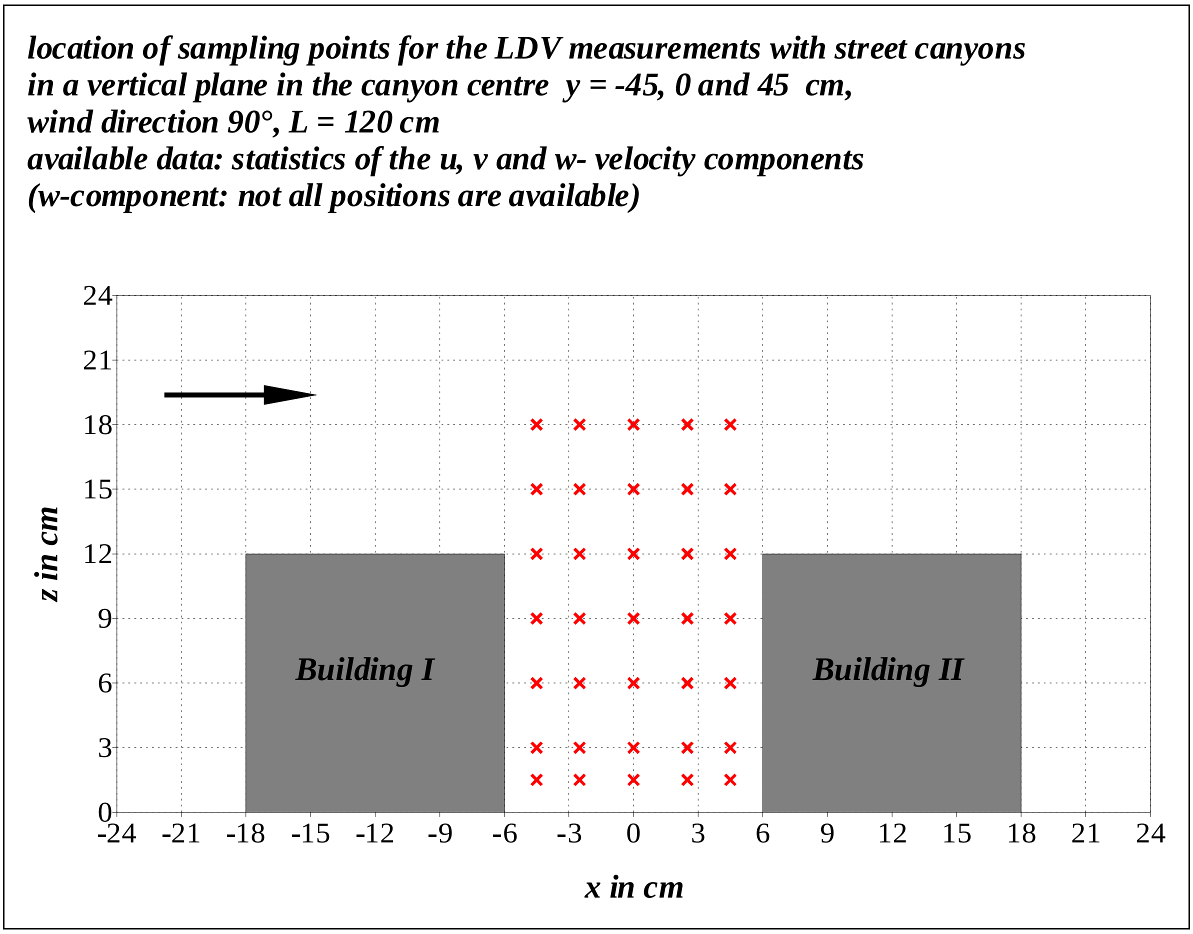
P. Kastner-Klein, E.J. Plate, 1999: Wind-tunnel study of concentration fields in street canyons, *Journal of Atmospheric Environment*, ***33***, 3973-3979.

P. Kastner-Klein, 1999: Experimentelle Untersuchung der strömungsmechanischen Transportprozesse in Straßenschluchten**.** Doctor thesis at the faculty of Civil Engineering, University of Karlsruhe (in press).

Appendix 1: Sketches of investigated roof configurations

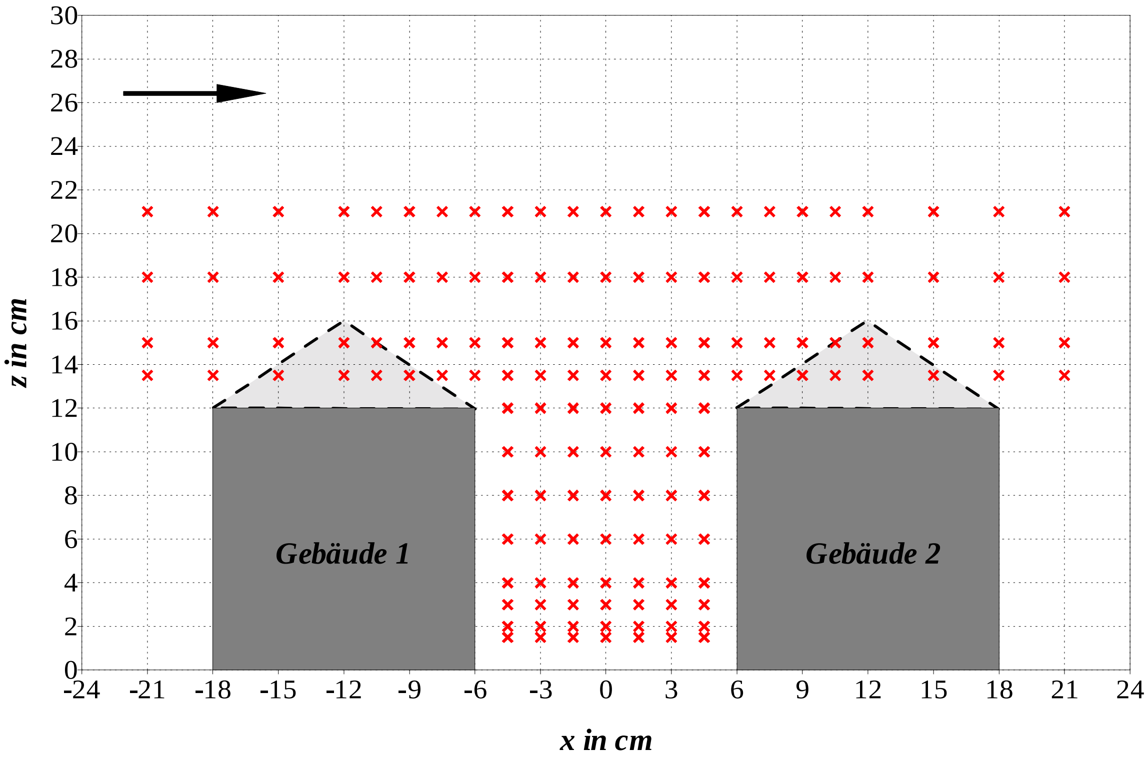


Appendix 2: Location of sampling points during the flow field measurements for the vehicle induced turbulence study – vertical plane at *y* = -45, 0 and 45 cm

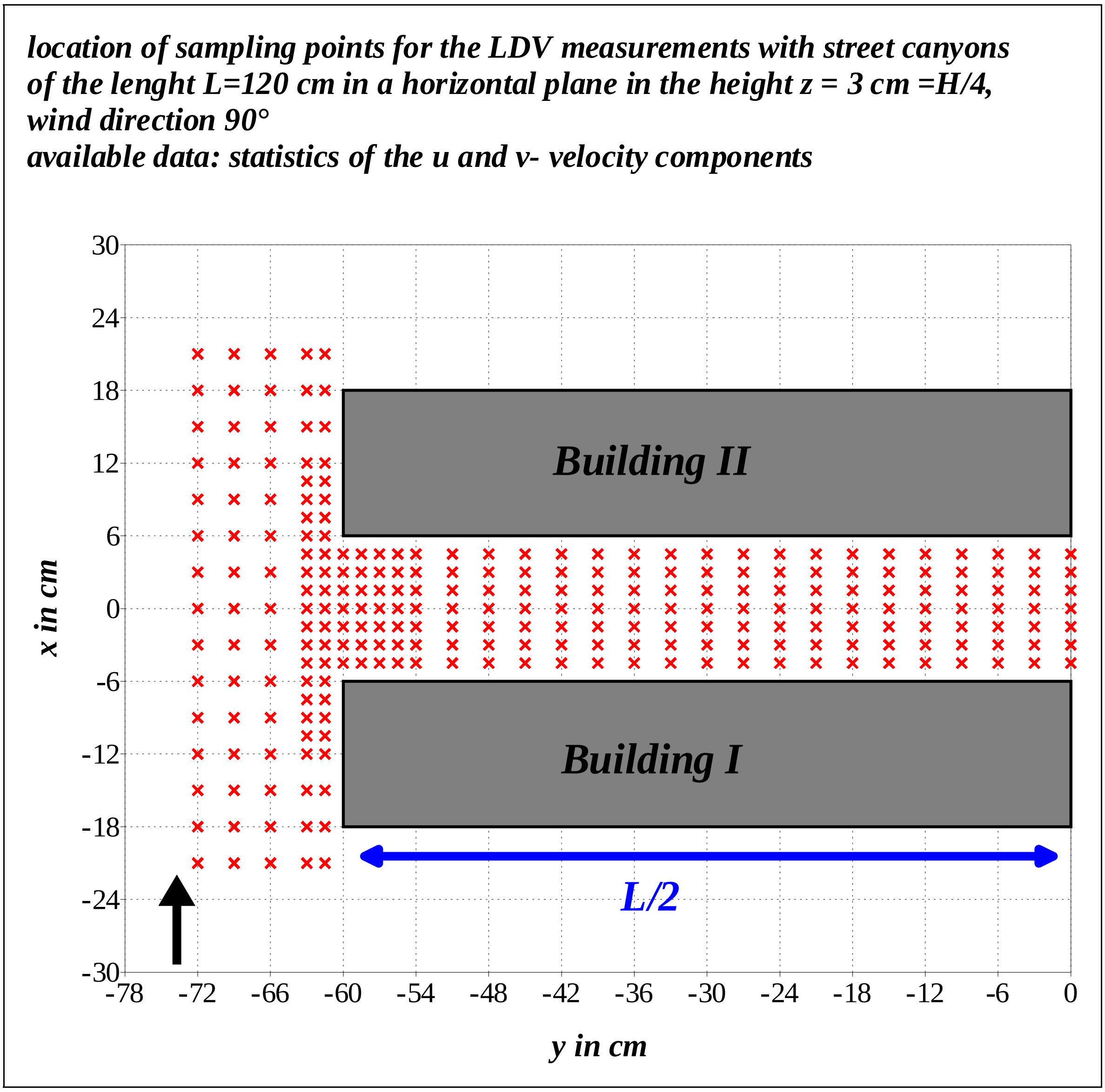


Appendix 3: Location of sampling points during the flow field measurements for the building and roof geometry study – vertical plane at *y* = 0 cm

location of sampling points for the LDV measurements with street canyons in a vertical plane in the canyon centre y = 0 cm = L/2, wind direction 90° available data: statistics of the u, v and w- velocity components (w-component: not all positions are available)

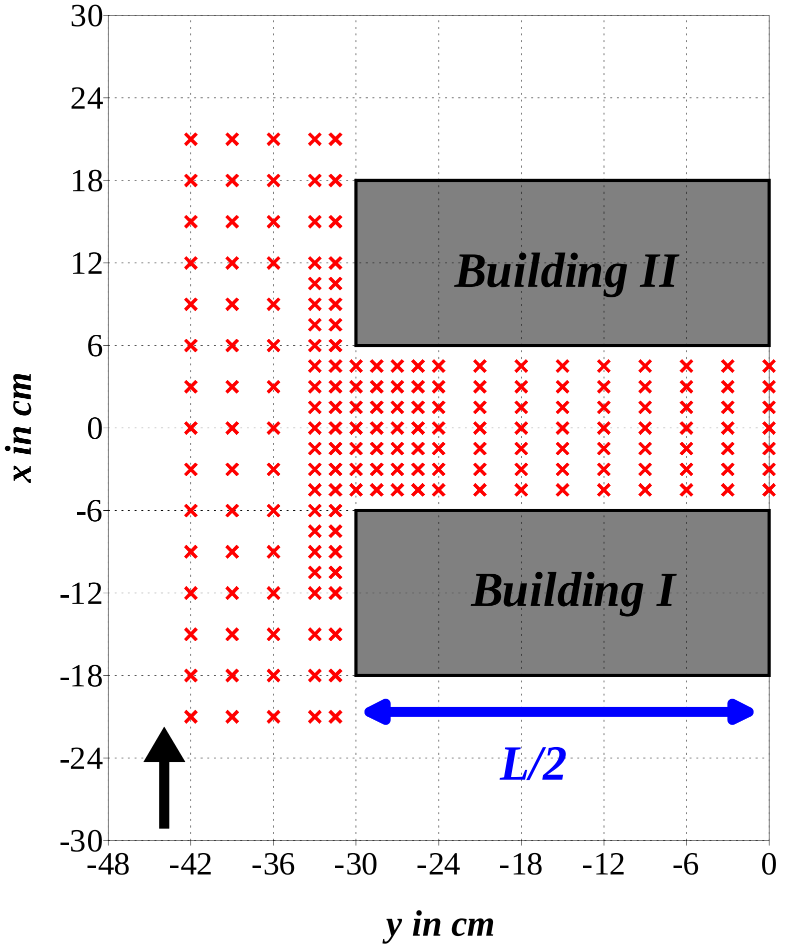


Appendix 4: Location of sampling points during the flow field measurements for the building and roof geometry study – horizontal plane at *z* = 0 cm, *L* = 120 cm

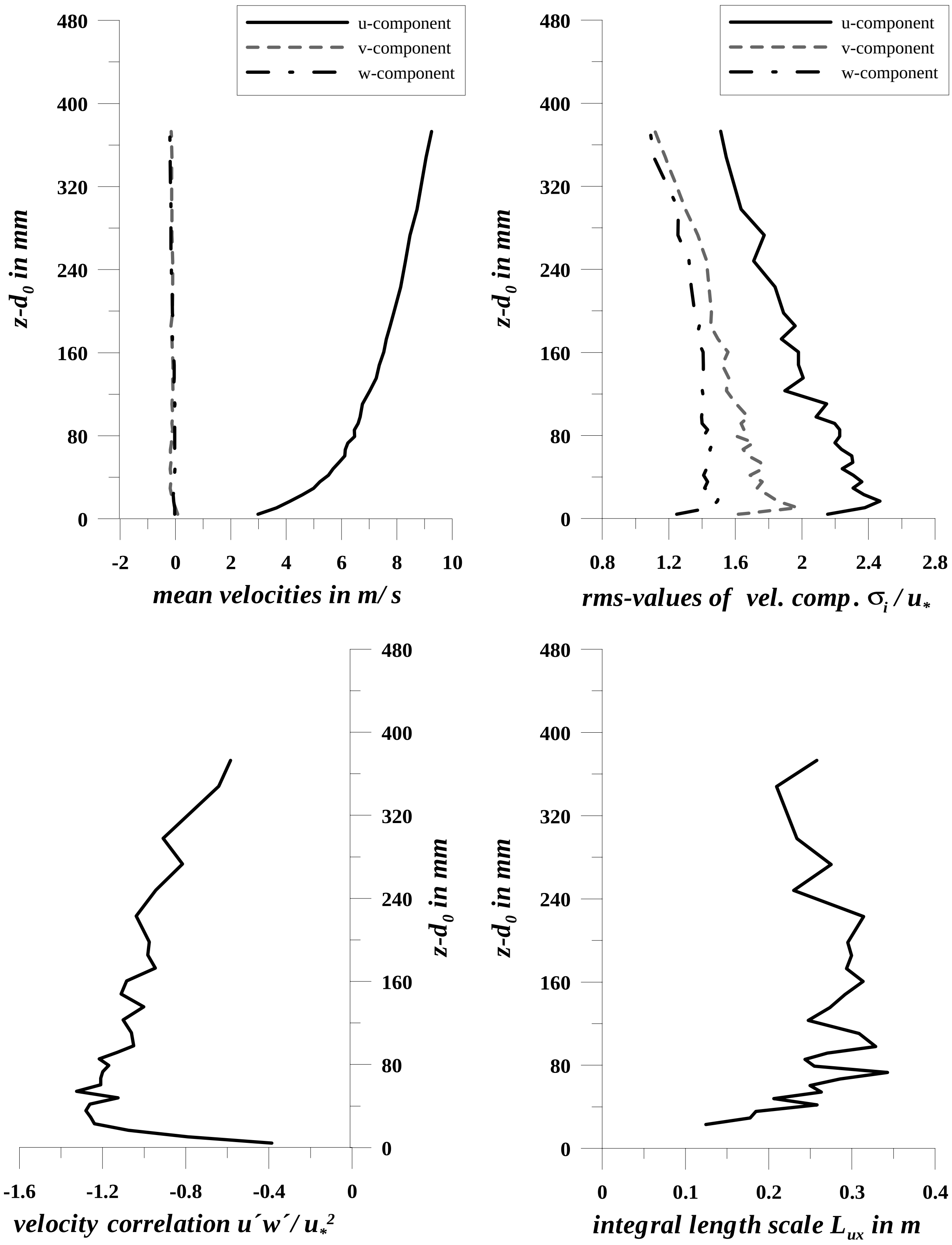


Appendix 5: Location of sampling points during the flow field measurements for the building and roof geometry study – horizontal plane at *z* = 0 cm, *L* = 60 cm

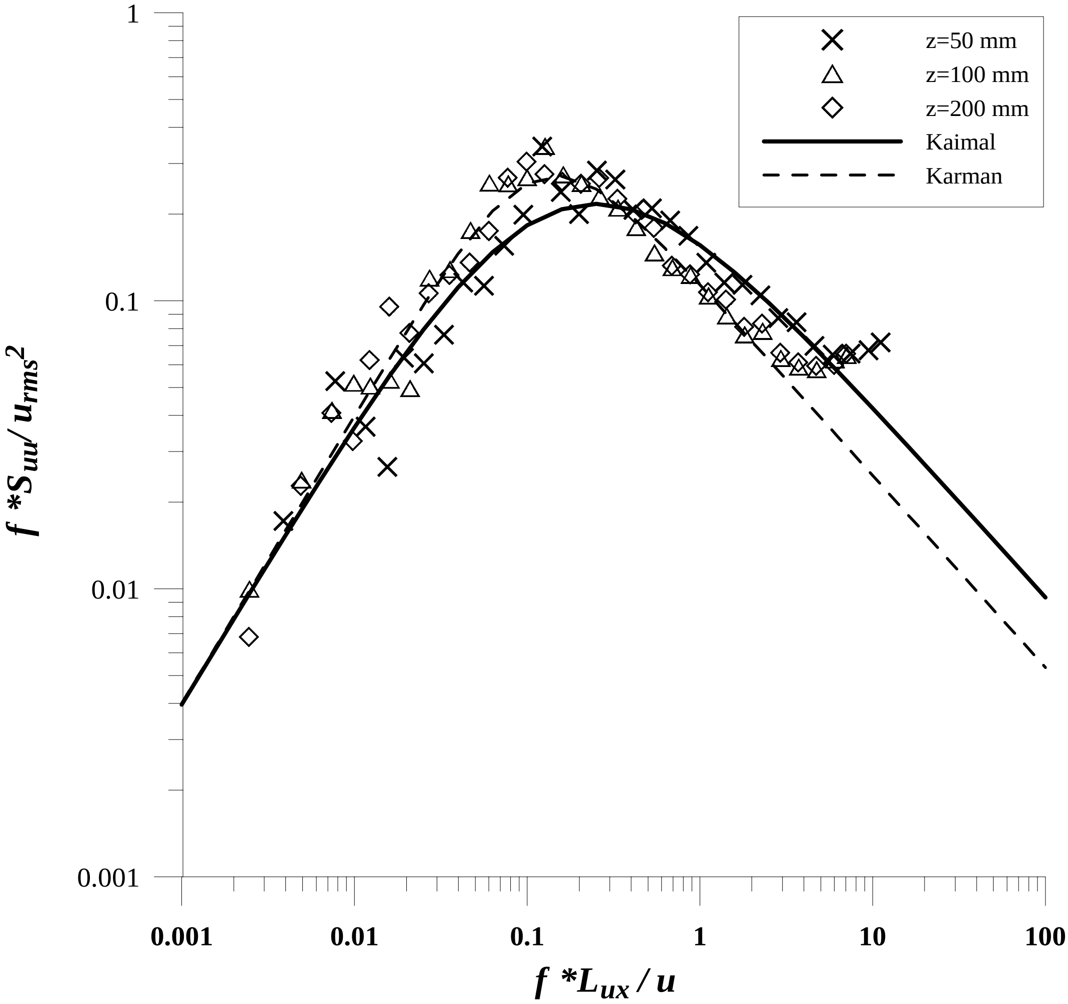
location of sampling points for the LDV measurements with street canyons of the lenght L=60 cm in a horizontal plane in the height z = 3 cm =H/4, wind direction 90°
available data: statistics of the u and v- velocity components



Appendix 6: Documentation of the boundary layer characteristics in wind tunnel of the University of Karlsruhe



Appendix 7: Documentation of spectra in the wind-tunnel boundary layer



Tab. 1: Description of building configurations of the dispersion studies.

General description	Installed buildings				Building geometry			Wind direction	Roof configuration	Name of file
	I	II	III	IV	*L*	*B1*	*B2*			
2D-sit., reference case	yes	yes	no	no	180 cm	12 cm	12 cm	90°	flat – flat	FF180121290
Variation of building length	yes	yes	no	no	120 cm	12 cm	12 cm	90°	flat – flat	FF120121290
	yes	yes	no	no	60 cm	12 cm	12 cm	90°	flat – flat	FF060121290
Variation of building width	yes	yes	no	no	180 cm	6 cm	12 cm	90°	flat – flat	FF180061290
	yes	yes	no	no	180 cm	18 cm	12 cm	90°	flat – flat	FF180181290
	yes	yes	no	no	180 cm	24 cm	12 cm	90°	flat – flat	FF180241290
	yes	yes	no	no	180 cm	6 cm	6 cm	90°	flat – flat	FF180060690
	yes	yes	no	no	180 cm	12 cm	6 cm	90°	flat – flat	FF180120690
	yes	yes	no	no	180 cm	18 cm	6 cm	90°	flat – flat	FF180180690
	yes	yes	no	no	180 cm	24 cm	6 cm	90°	flat – flat	FF180240690
Influence of additional buildings	yes	yes	yes	no	180 cm	12 cm	12 cm	90°	flat – flat – flat	3F180121290
	yes	yes	yes	yes	180 cm	12 cm	12 cm	90°	flat – flat – flat - flat	4F180121290
	yes	yes	yes	no	120 cm	12 cm	12 cm	90°	flat – flat – flat	3F120121290
	yes	yes	yes	yes	120 cm	12 cm	12 cm	90°	flat – flat – flat - flat	4F120121290

Variation of wind direction	yes	yes	no	no	120 cm	12 cm	12 cm	75°	flat – flat	FF120121275
	yes	yes	no	no	120 cm	12 cm	12 cm	60°	flat – flat	FF120121260
	yes	yes	no	no	120 cm	12 cm	12 cm	45°	flat – flat	FF120121245
	yes	yes	no	no	120 cm	12 cm	12 cm	30°	flat – flat	FF120121230
	yes	yes	no	no	120 cm	12 cm	12 cm	15°	flat – flat	FF120121215
	yes	yes	no	no	120 cm	12 cm	12 cm	0°	flat – flat	FF120121200
	yes	yes	no	no	60 cm	12 cm	12 cm	75°	flat – flat	FF060121275
	yes	yes	no	no	60 cm	12 cm	12 cm	60°	flat – flat	FF060121260
	yes	yes	no	no	60 cm	12 cm	12 cm	45°	flat – flat	FF060121245
	yes	yes	no	no	60 cm	12 cm	12 cm	30°	flat – flat	FF060121230
	yes	yes	no	no	60 cm	12 cm	12 cm	15°	flat – flat	FF060121215
	yes	yes	no	no	60 cm	12 cm	12 cm	0°	flat – flat	FF060121200

Variation of roof geometry	yes	yes	no	no	180 cm	12 cm	12 cm	90°	flat – downward wedge	FD180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	flat – upward wedge	FU180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	flat – triangle	FT180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	flat – rectangle	FR180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	downward wedge - flat	DF180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	upward wedge - flat	UF180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	triangle - flat	TF180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	rectangle - flat	RF180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	downward – upward wedge	DU180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	upward – upward wedge	UU180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	upward – downward wedge	UD180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	downward – downward wedge	DD180121290
	yes	yes	no	no	180 cm	12 cm	12 cm	90°	triangle – triangle	TT180121290
	yes	yes	no	no	120 cm	12 cm	12 cm	90°	flat – triangle	FT120121290
	yes	yes	no	no	120 cm	12 cm	12 cm	90°	triangle - flat	TF120121290
	yes	yes	no	no	120 cm	12 cm	12 cm	90°	triangle – triangle	TT120121290
	yes	yes	no	no	60 cm	12 cm	12 cm	90°	flat – triangle	FT060121290
	yes	yes	no	no	60 cm	12 cm	12 cm	90°	triangle - flat	TF060121290
	yes	yes	no	no	60 cm	12 cm	12 cm	90°	triangle – triangle	TT060121290

Degenerated street canyons	yes	no	no	no	180 cm	12 cm	--	90°	flat - no	FN180120090
	no	yes	no	no	180 cm	--	12 cm	90°	no – flat	NF180001290
	yes	no	no	no	120 cm	12 cm	--	90°	flat - no	FN120120090
	no	yes	no	no	120 cm	--	12 cm	90°	no – flat	NF120001290
	yes	no	no	no	60 cm	12 cm	--	90°	flat - no	FN060120090
	no	yes	no	no	60 cm	--	12 cm	90°	no – flat	NF060001290

Tab. 2: Description of available flow field data (wind direction 90°)

General description	**Installed buildings**				**Building geometry**			**Type of measurements**	**Comments**	**Name of file in brackets: amount of data points)**	
	I	**II**	**III**	**IV**	***L***	***B1***	***B2***			**uv-component**	**wv-component**
Vehicle induced turbulence study	yes	yes	no	no	120 cm	12 cm	12 cm	Profile measurements of all 3 velocity components in 3 vertical planes at y=-45, 0, 45 cm (see Appendix 2)	Flat roofs, different kind of traffic motions: no moving obstacles, one-way traffic or two-way traffic, different kind of obstacles	a list of files is available on request	
Variation of building length and roof geometry study	yes	yes	no	no	180 cm	12 cm	12 cm	Profile measurements of all 3 velocity components in the vertical plane y=0 cm (see Appendix 3)	flat – flat	uvffl1.dat (148)	wvffl1.dat (124)
									triangle - flat	uvsfl1.dat (141)	wvsfl1.dat (113)
									triangle – triangle	uvssl1.dat (134)	wvssl1.dat (36)
	yes	yes	no	no	120 cm	12 cm	12 cm	Profile measurements of all 3 velocity components in the vertical plane y=0 cm (see Appendix 3)	flat – flat	uvffl2.dat (148)	wvffl2.dat (124)
									triangle - flat	uvsfl2.dat (141)	wvsfl2.dat (113)
									triangle – triangle	uvssl2.dat (134)	wvssl2.dat (36)
								Measurements of the horizontal velocity components in a horizontal plane z=3 cm (see Appendix 4)	flat – flat	z30ffl2.dat (252)	
									triangle - flat	z30sfl2.dat (252)	
									triangle – triangle	z30ssl2.dat (252)	

	yes	yes	no	no	60 cm	12 cm	12 cm	Profile measure-ments of all 3 velocity compo-nents in the vertical plane y=0 cm (see Appendix 3)	flat – flat	uvffl3.dat (148)	wvffl3.dat (124)
									triangle - flat	uvsfl3.dat (141)	wvsfl3.dat (113)
									triangle – triangle	uvssl3.dat (134)	wvssl3.dat (36)
	yes	yes	no	no	60 cm	12 cm	12 cm	Measurements of the horizontal velocity compo-nents in a horizontal plane z=3 cm (see Appendix 5)	flat – flat	z30ffl3.dat (182)	