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HARMFUL GAS DISPERSION IN COMPLEX TERRAIN

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Abstract: *Experiments on gas dispersion modeling in boundary layer wind tunnel were and will be performed in order to verify a software for modeling of gas dispersion in urban area and complex terrain, which is being developed in VZLU.*

Keywords: ***Gas dispersion, wind tunnel modeling, boundary layer, flame ionization detector***

1. Introduction

Expansion of human society has negative impacts on the environment. Atmospheric boundary layer is one of the most endangered spheres. Humans living in cities are threatened with different types of gas pollution, i.e. transport emissions, local furnaces and industrial emissions. Probably most dangerous case is an industrial accident or terrorist attack with massive harmful gas leakage into the atmosphere. Prediction of gas dispersion and concentration in nearby area of possible sources of harmful gases is therefore important and may save lives, health and material values.

2. Physical modeling

Physical modeling is an experimental technique, which uses building models and wind tunnel in order to simulate flow in Earth boundary layer as precise as possible. This technique is often used for verification and comparison of results from mathematical modeling. Mathematical modeling by the means of CFD (Computational fluid dynamics) is nowadays a primary tool for gas dispersion research. However, computer modeling requires real initial and boundary conditions in order to create valid results. These conditions can be provided using measurements in wind tunnel. Afterwards, physical modeling with same models as in computer modeling is used to compare the results of both methods and verify that computer calculations are correct and as precise as possible.

Physical modeling of gas dispersion has been performed in VZLU since 2002, e.g. Jirsák & Ulman (2003), Ulman et al. (2005), Ulman (2010).

2.1. Similarity conditions and simulation tools

Physical modeling is based on a principle of similarity between flow in atmospheric boundary layer and flow in so-called boundary layer wind tunnel (BLWT). BLWT in VZLU is able to simulate geometric similarity and dynamic flow similarity, which has to be adhered in order to get correct results. Guidelines for gas emission modeling were proposed by Snyder (1981).

The BLWT in VZLU is an open circuit wind tunnel with 55 kW fan and 1,8 x 1,5 m cross section. The test section where boundary layer develops is 13,6 m long. Maximum flow velocity above the boundary layer is 25 $m.s^{-1}$. Model section is 2 m long and contains a turntable, where wind direction impacting the model can be changed. Velocity above the boundary layer is monitored by Pitot-static tube and hot-wire transducer probe. Static pressures along the entire wind tunnel are monitored as well using pressure transducers.

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The used boundary layer simulates suburban areas according to Eurocode 1 (2007). Its mean velocity profile is described with logarithmic distribution (Jirsák & Ulman, 2001). The logarithmic law is defined for indifferent atmospheric layering as

$$U(z) = \frac{u*}{k} \cdot \ln\left[\frac{z-d}{z_o}\right] \quad (1)$$

where u* is frictional velocity (dynamic velocity) [m/s], k = 0.4 is von Karman's constant, z_0 is frictional height (aerodynamic roughness) [m], d is zero plane displacement [m], U refers to mean velocity [m/s] and z is vertical coordinate [m].

The condition of flow similarity involves overcritical Reynolds roughness number Re* = z0.u*/ν ≥ 2,5, where ν is cinematic viscosity of air, ca. $15*10^{-6}$ m^2/s. For the purpose of gas dispersion modeling this condition can be relaxed up to Re* ≥ 1,0 according to publication ASCE No.67 (1999). Turbulent boundary layer is created with rectangular barrier 140 mm high at the beginning of working section and with roughness field 13 m long made of plastic insulation sheet with 7 mm high truncated cones placed on the working section floor, which contributes to create fully developed turbulent boundary layer entering the model section.

Velocities in boundary layer measured by means of hot-wire anemometer Dantec Dynamics Streamline with dual-sensor probe are presented at Figure 1. Here $U_€$ refers to a reference velocity above the boundary layer (5 $m.s^{-1}$), U and V to longitudinal and transversal mean velocity component and I_u to intensity of turbulence. Negative value of V means its reverse orientation of this velocity component.

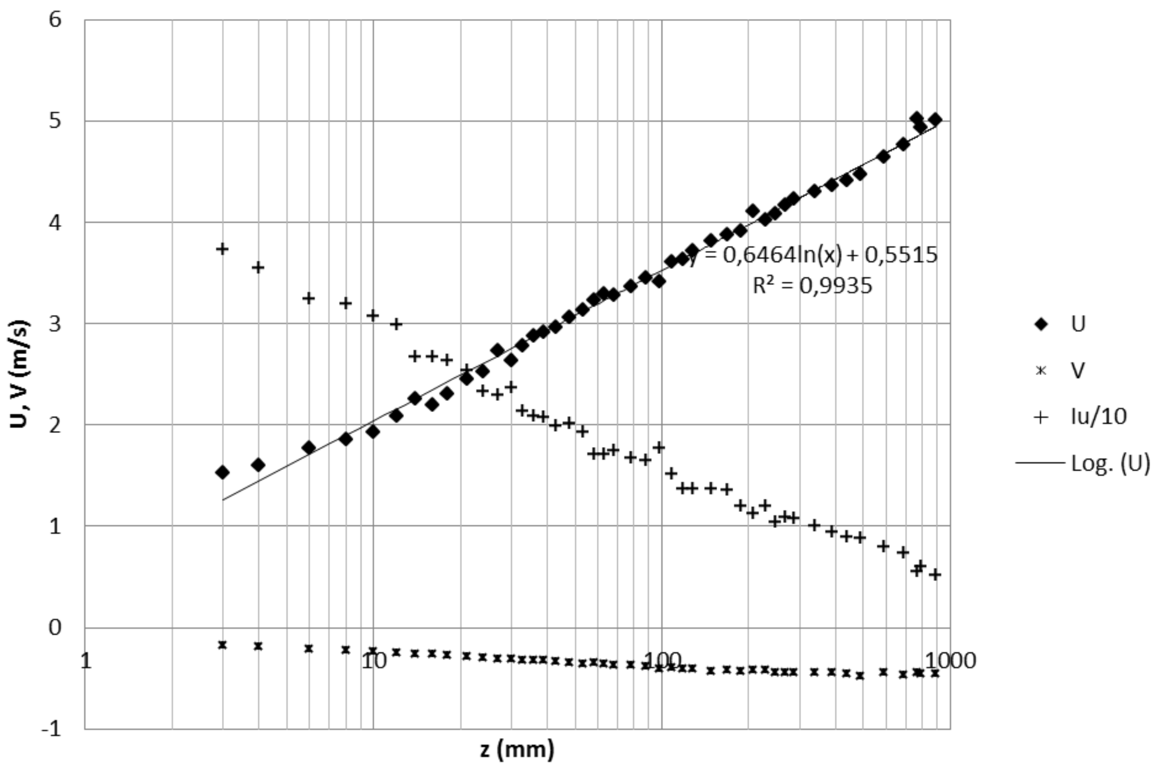

Figure 1 Vertical velocity profile

3. Experimental setup and results

In order to simulate gas leakage near ground level, small chamber sized 30x30x15 mm with filtration fabric on top was placed in the turntable centre in tunnel floor. This point source can simulate continuous leakage of gases into the atmosphere. Its flow properties were published in Michálek & Zacho (2012). Used tracer gas dosaged into source was ethane C_2H_6. For simulation of non-buoyant gas emission compressed air is used, for heavier-than-air gas emission sulfur hexafluoride SF_6 is used. These gases were dosaged by electronic flow controller Alicat and then mixed together and released via tubing into the source. Volume flow of air or SF_6 was changed in the range 1,3 – 3,0 $l.min^{-1}$ in order to get different flow momentum emitted from the source. SF_6 is a gas with ca. 5-times higher density than air, therefore its momentum is higher than for air with the same volume flow. Ethane volume flow was changed in the range 0 – 2,5 $l.min^{-1}$ at steps of 0,25 $l.min^{-1}$ in order to study the influence of its increasing concentration on the results.

Tracer gas concentration was measured on a simple rectangular building sized 170x170x60 mm made of duralumin and equipped with eight taps placed on model vertical centerline (see Fig.2), six on a wall and two on a roof. Smaller numbers in the figure indicate tap distances in mm. These taps were connected via capillary tubes to four flame ionization detectors FID-80 with electrometers, which measure tracer gas concentration and convert it into an electric signal, which can be recorded in computer. Measuring software was programmed using National Instruments LabView 2011 environment, which allows reading data from A/D card, recording the signal and calculating all necessary values. Calibration of the FIDs was made using calibration gases with known concentration 100 ppm and 1000 ppm of ethane in air.

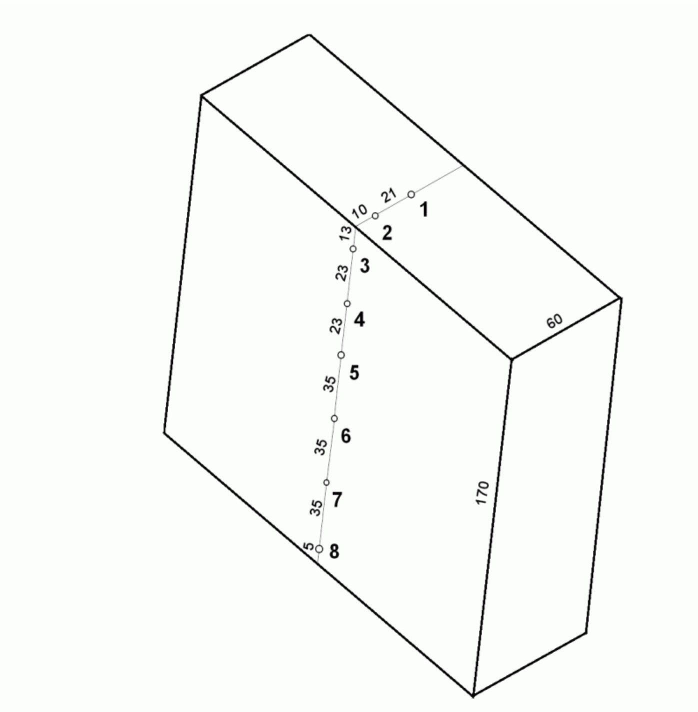

Figure 2 Experimental building model

Fig. 3 shows the model installed in wind tunnel and the source installed in the center of the turntable in front of the model. The model was installed at distance 0,5 H or 1H beyond the source, where H = 170 mm is the model building height. Measuring concentration on windward and leeward side of the model was made possible by rotating the model in 180-degree angle.

The frequency response of used tubing and FIDs is up to 10 Hz, so the sampling rate was set to 100 Hz. Measuring time for one record was 60 s. In order to monitor background concentration, one FID was connected to a tube ending at wind tunnel wall at sufficient distance above the experimental area, but still in wind tunnel flow.

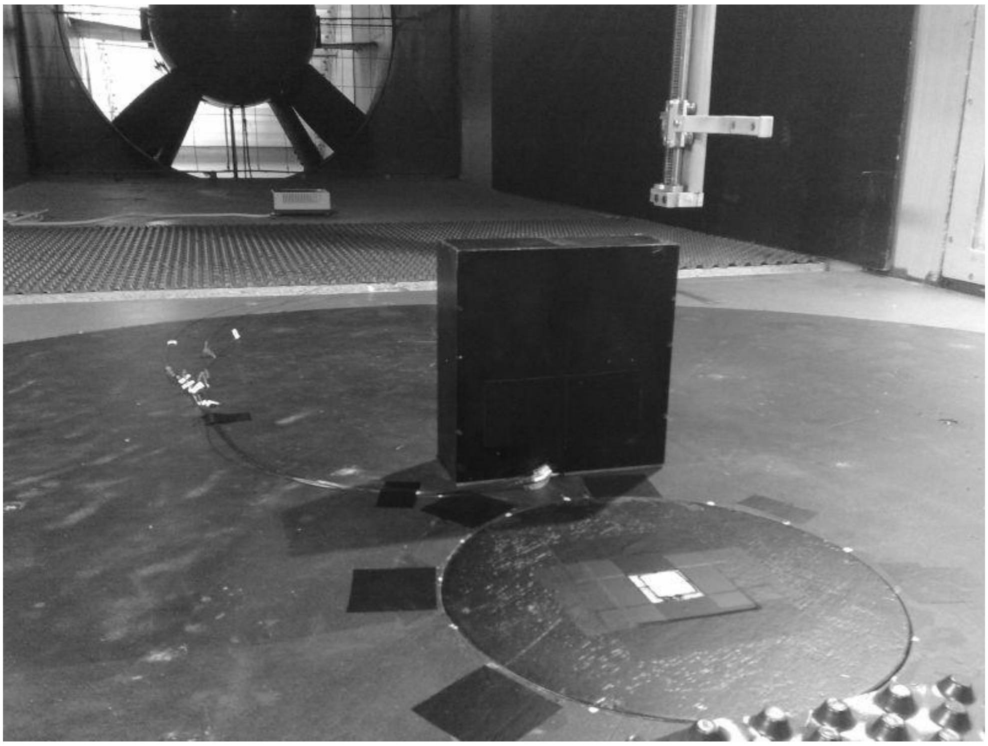

Figure 3 Model and source in wind tunnel

For the purpose of data analysis and graph plotting, the software Origin 8 was used. Tracer gas concentrations were recalculated into dimensionless concentration C/C0, where C0 was initial concentration in ppm of tracer gas entering the source via plastic tube. Position of the sampling taps was expressed in fraction z/H, where z is the height of sampling tap above tunnel floor and H is model building height. Taps No.1 and 2 located on the roof have the value of z=H+31mm (z/H=1,18) and z=H+10mm (z/H=1,06). The first point in graphs with value of z/H=0 is the background ethane concentration, which was measured on tunnel side wall at height approx. 0,5 m. Ergo the tap numbers plotted on graphs on horizontal axis are from left to right: background, tap No.8 to No.1.

Fig. 4 presents measured concentration on model with taps oriented on windward side for different initial concentration emitted from the source in distance 1H and with neutral emission. SLPM stands for "standard liters per minute", which means flow rate set by the flow controller and corrected for standard pressure of the gas 1 atmosphere and temperature 25 °C. Negative concentrations should be considered as zero, these values occur probably due to inaccuracy of calibration and measuring. Figure 5 presents the same situation as figure 4 except that the building was rotated in 180 degree angle therefore the wall taps are located on leeward side. Significant differences in results between these two basic cases can be seen, i.e. concentrations on windward side are much lower, in the central part of the windward wall are nearly zero, but near ground and on the roof there remains relative high concentration. The concentrations on leeward wall remain high and decrease slowly from ground to the top. This may happen due to strong turbulent mixing in the wake of the model. Similar results were observed with heavy emission as presented at figures 6 and 7.

Figure 8 shows concentration measured on leeward wall in case of constant volume flow of emission and increasing wind tunnel velocity. One can see that concentration slowly decreases with increasing velocity in wind tunnel, but the background concentration does not change.

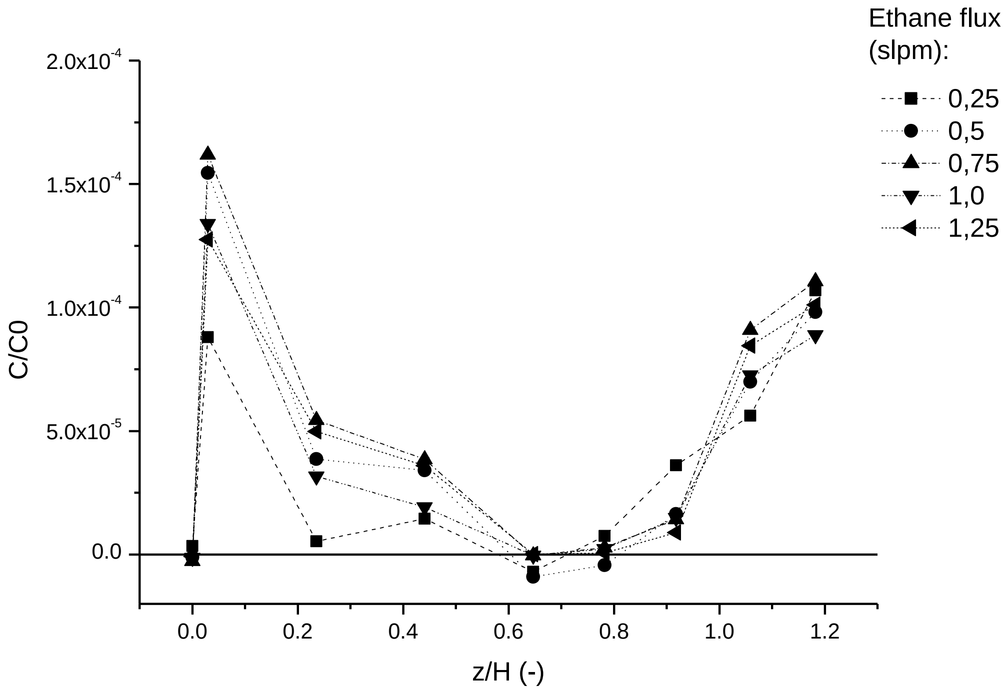

Figure 4 Windward side, neutral emission

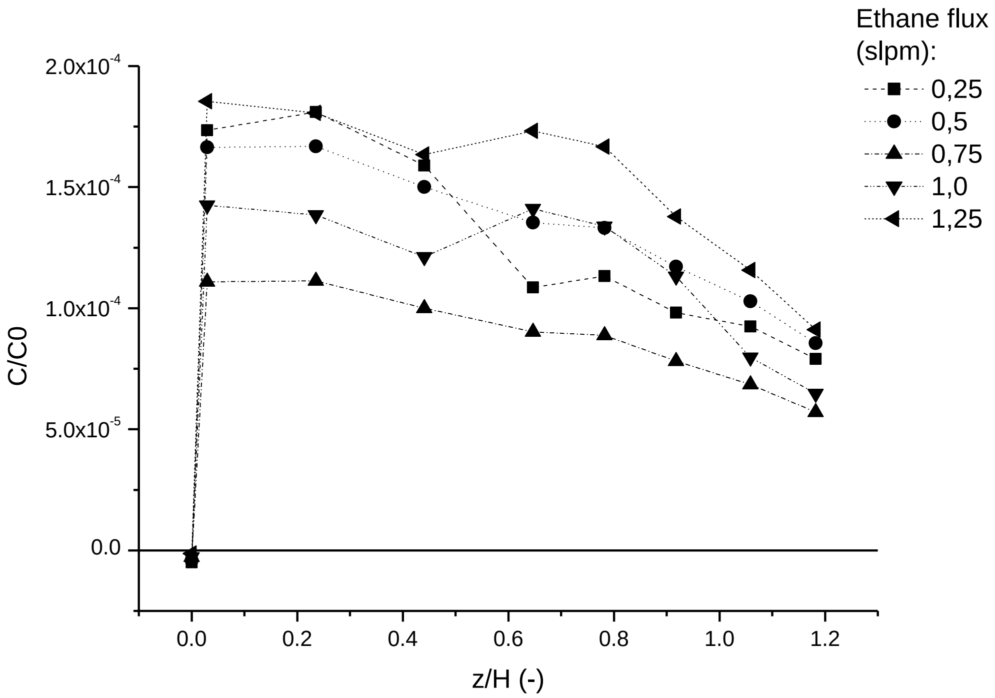

Figure 5 Leeward side, neutral emission

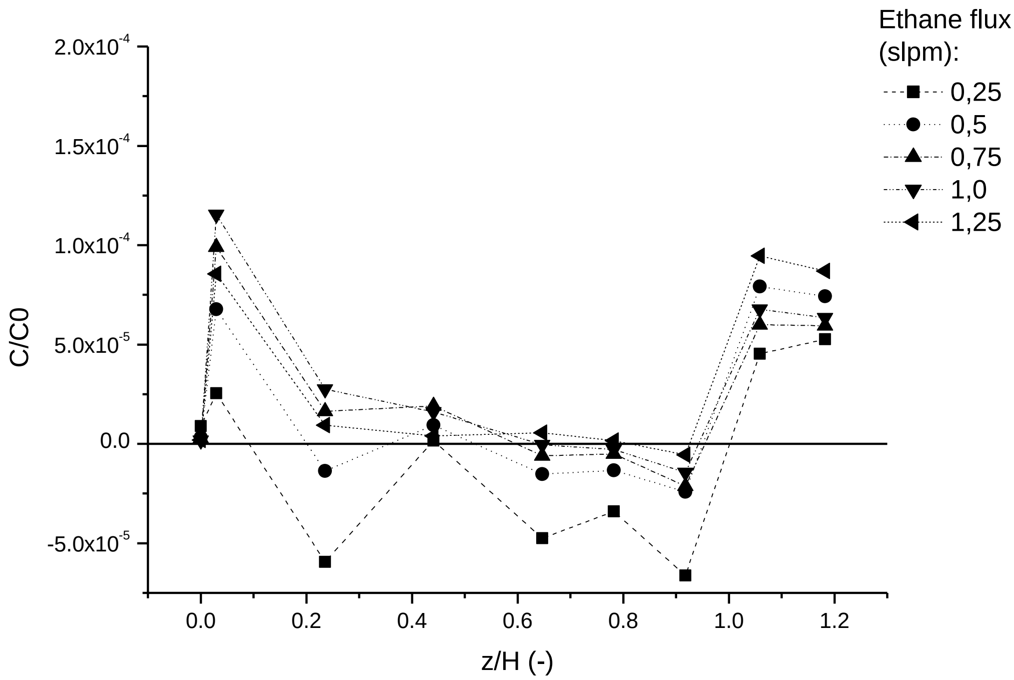

Figure 6 Windward side, heavy emission

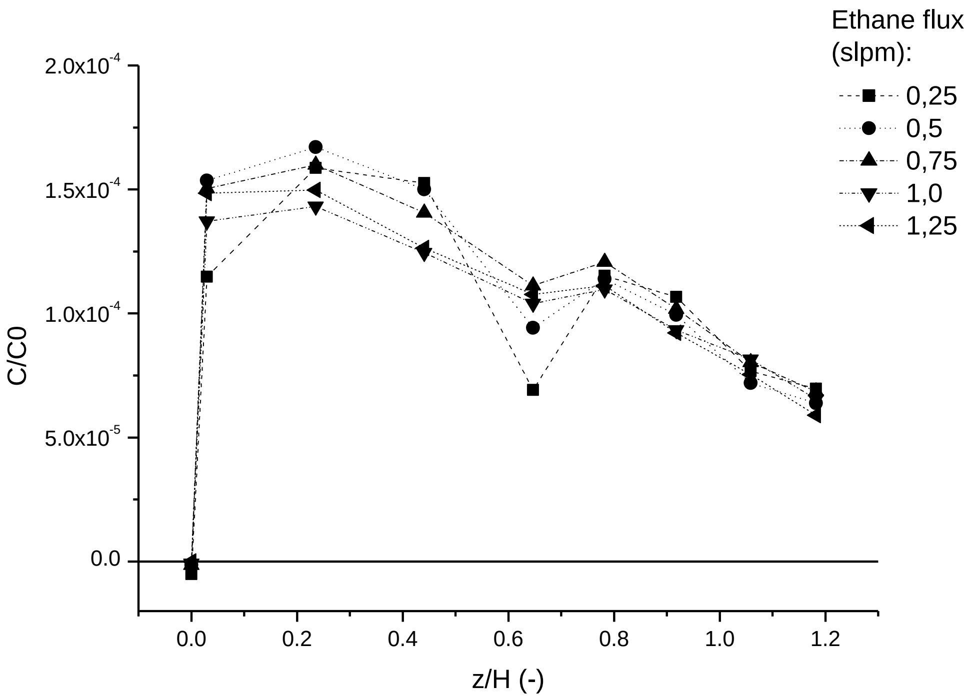

Figure 7 Leeward side, heavy emission

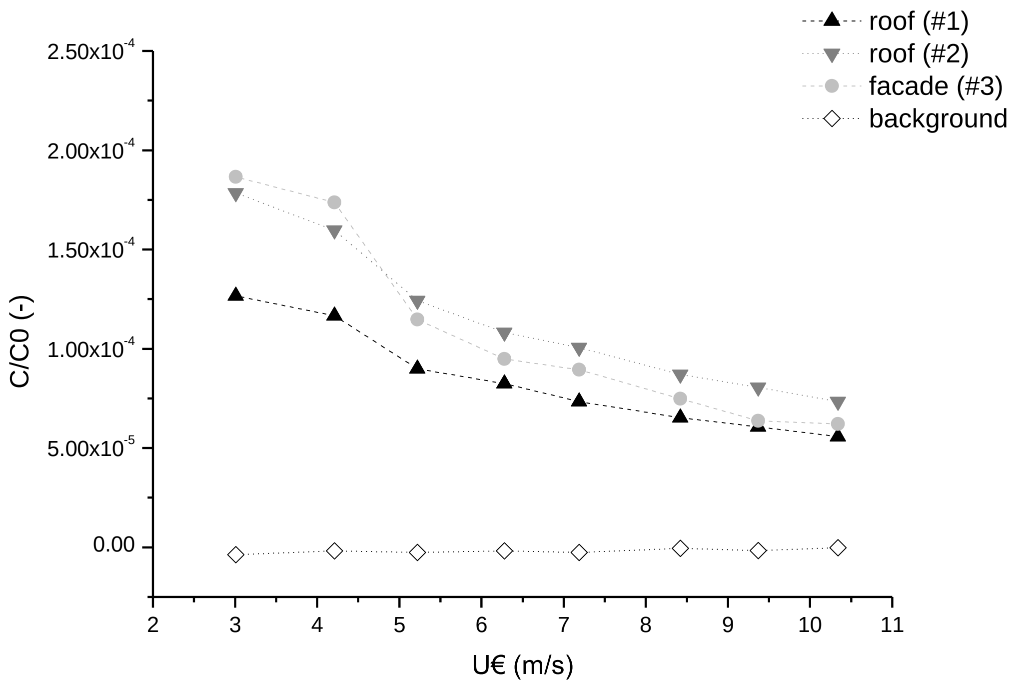

Figure 8 Effect of flow velocity, leeward side

4. Conclusions

Gas concentrations on a rectangular building model were measured in a boundary layer wind tunnel. These measurements will serve as boundary conditions and verification for newly developed software calculating gas dispersion in chosen urban areas including complex terrain configuration. Different results on windward and leeward wall of the model have been observed, i.e. concentration on leeward wall are higher than on windward wall, while concentrations near ground and on the roof do not differ too much in the case of neutral or dense emission.

Future experiments will be focused on dispersion between groups of buildings and in complex terrain in chosen urban areas where existing industrial plants present a risk of release of dangerous gases. These current and future experiments will help to verify and test the new software for gas dispersion modeling in these urban areas.

Acknowledgement

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