Measurements of Traffic-Induced Turbulence within a Street Canyon during the Nantes '99 Experiment

G. Vachon*, P. Louka, J-M. Rosant, P.G. Mestayer, J-F. Sini

**Laboratoire de Mécanique des Fluides UMR 6598 CNRS - Ecole Centrale de Nantes, 1 rue de la Noë, BP 92101, F-44321 Nantes Cedex 3*

1. Introduction

The pollutant dispersion in a street canyon is influenced by several parameters such as wind direction, wind speed, temperature and traffic conditions. Many studies on dispersion of vehicular emission in an urban street canyon have been conducted (Louka et al., 2000-a; Väkevä et al., 1999; Bauman et al., 1982) but only a few full-scale or wind-tunnel experiments are focused on turbulence induced by traffic within the street. Qin & Kot (1993) observed a great influence of the movement of the vehicle fleet on the airflow and turbulence near the bottom of the canyon and considered that the vehicle wake and the hot exhaust gases generate mechanical and thermal turbulence. They could measure the influence of vehicle movements on airflow in the canyon up to 12 m above the road surface. DePaul & Sheih's (1986) observations indicate that additional turbulence generated by traffic has a marked influence on the turbulent velocity distribution up to a height of approximately 7 m. Recently, Kastner-Klein et al. (1998) studied the traffic-induced turbulence on concentration fields within a canyon by means of wind-tunnel experiments. The moving traffic leads to a pronounced transport of pollutants along the canyon axis. It also appears that the turbulence in the street has an evident diurnal variation which follows that of the traffic quite well, and that the pollutant concentrations may decrease when the traffic increases due to turbulence created by the vehicle motion. The effect of traffic on turbulence within a street canyon was measured during the Nantes '99 experiment and is investigated in this paper.

2. Methodology

The Nantes '99 experiment was a full-scale experiment performed in the centre of the city of Nantes (France) and took place in June-July 1999. The Rue de Strasbourg is a three-lane street canyon with approximately North-South (332°) orientation. It is a high-traffic one-way street, with a great homogeneity in building construction and its aspect ratio, street width over buildings mean height, is W/H = 0.7 where H, the mean height of the buildings, is approximately 21 m. The flow components and turbulence were measured by 3-D sonic anemometers at three levels on each side of the street : z/H = 0.07, 0.19 and 0.69 at the west side and z/H = 0.07, 0.19 and 0.5 at the east side of the street (z is the height above road level). Carbon monoxide, CO, chosen as the car pollutant emission tracer, was measured at the same levels as the wind within the street. Traffic (number of vehicles and their velocity) was measured at eight different places within the street and within the lateral streets. Reference wind and background pollution were measured on the roof of the west building at z/H = 1.28 (Figure1.1). The air temperature and the temperature of the walls were measured also within the street and their analysis is presented in an accompanying paper (Louka et al., 2001). A detailed description of the experimental set-up is given in Vachon et al. (1999). In order to study traffic-induced turbulence, four days have been selected amongst the hourly periods with low wind speed (Uref < 1.2 m.s^{-1}) to minimise the effect of wind created turbulence and with a reference wind normal to the street axis coming from the East (62° ± 30° from the North) (Table 1.1). The recirculation wind speed is lower in the street when the reference wind is normal to the street axis than when oblique or parallel. Measurements performed in Copenhagen, Denmark (Berkowicz et al., 1996) and in Guangzhou, South China (Qin & Kot, 1993) showed that in the case of a low wind speed, when the thermal stratification is important, the airflow created by the vehicle motion is evident and the traffic-induced turbulence seemed to be the dominant mixing mechanism .

3. Results and Discussion

Figures 2.1 and 2.2 display the turbulent kinetic energy (TKE) within the street, where TKE_{ref} is the turbulent kinetic energy measured at the roof level. In a situation without traffic a decrease in TKE appears as the ambient air enters the canyon due to the dissipation of kinetic energy into heat. Moreover, when the reference wind is perpendicular to the street axis a vortex develops within the street (Dabberdt et al., 1973) and therefore, in the case without traffic, TKE is expected to be weaker at the leeward side than at the windward side due to dissipation. Figures 2.1 and 2.2 show that TKE measured on the leeward side is greater than on the windward side in the lower part of the street (z/H=0.07); also a strong increase of TKE on the windward side, very close to the vehicles, may be observed. Therefore, traffic increases the TKE in the lower part of the street (on the leeward and windward sides). Furthermore, air flows over the traffic lanes before reaching the leeward side of the street, which generates a production of TKE on the leeward side by traffic. Figure 2.3 illustrates the TKE dependence on the number of vehicles. The influence of traffic on TKE is more obvious at z/H=0.07 and z/H=0.19 (z=1.5 m and z=4 m respectively) on the leeward side of the street. TKE increases up to a threshold value of approximately 350 – 400 vehicles per hour per lane and then decreases. Above this value the vehicles are close to each other and their velocity is low resulting to a blockage of further production of turbulence. On the other hand, the traffic-induced turbulence is not observable on the windward side. Figure 2.4 shows a great dependence of TKE on vehicle velocity. TKE increases for a value V_{cars}/U_{ref} greater than 10, which corresponds to a vehicle velocity of 35 $km.h^{-1}$. This behaviour is clear at z/H=0.07 and z/H=0.19 on the leeward side and at z/H=0.07 on the windward side. TKE also increases with vehicle velocity at z/H=0.19 windward side and at z/H=0.5 leeward side but in a lesser extent. The dependence of CO concentration on the number of vehicles per lane and per hour is shown in Figure 2.5: CO is low up to the threshold value of 300-350 vehicles and then a sharp increase is observed. This behaviour is mainly observed at the leeward side of the street up to z/H=0.5 but not on the windward side. From the above it is suggested that up to 350 vehicles per hour per lane, the vehicles motion creates an additional turbulence which is strong enough to disperse the vehicular exhausts. Figure 2.6 examines the direct influence of TKE on CO concentration. An increase in TKE leads to a decrease in CO concentration at all measuring locations.

4 Conclusion

Under low wind speed (U_{ref} < 1.2 $m.s^{-1}$) and wind direction perpendicular to the street axis, the measurements of the Nantes ’99 experiment show that additional turbulence is created by traffic at the lower levels of the street, at least up to 4 m high, and especially at the leeward side of the street. The turbulent kinetic energy is strongly associated with the number of vehicles and their velocity. It was indicated that a large number of vehicles (larger than 350-400 vehicles/lane/hour) leading to closer distance between them and smaller velocities is followed by a decrease in TKE. This traffic-induced turbulence has an effect on pollution dispersion since it reduces CO concentration especially at the low levels in the street.

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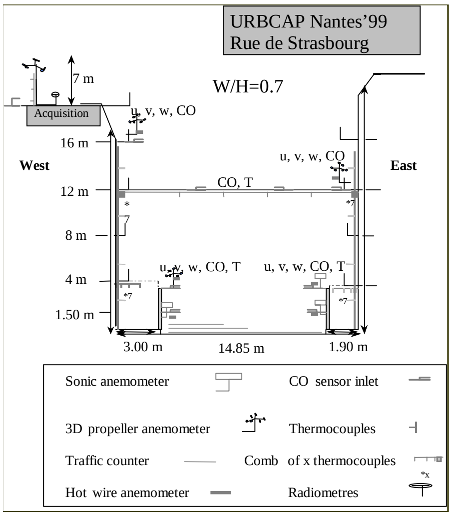

Figure 1.1. Sketch of the experimental site.

Table 1. 1 Selected periods with low reference wind speed and reference wind direction perpendicular to the street axis

n°	date	Local time	Reference wind speed (m.s^{-1})	Reference wind direction from the axis of the street (°)
1	22/06/99	8h45 – 9h45	0,75	67
2	22/06/99	17h00 – 18h00	0,75	96
3	23/06/99	9h15 – 10h15	0,83	68,5
4	23/06/99	12h00 – 13h00	0,83	95
5	23/06/99	13h30 – 14h30	0,85	109
6	23/06/99	18h00 – 19h00	1,05	94
7	24/06/99	9h30 – 10h30	1,10	97
8	25/06/99	9h00 – 10h00	1,00	98
9	25/06/99	10h00 – 11h00	1,05	99
10	25/06/99	11h00 – 12h00	1,13	95

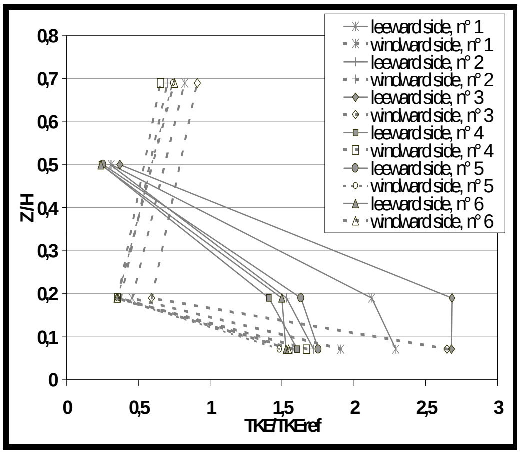

Figure 2.1 Turbulent kinetic energy within the street, the 22nd and 23rd of June 1999

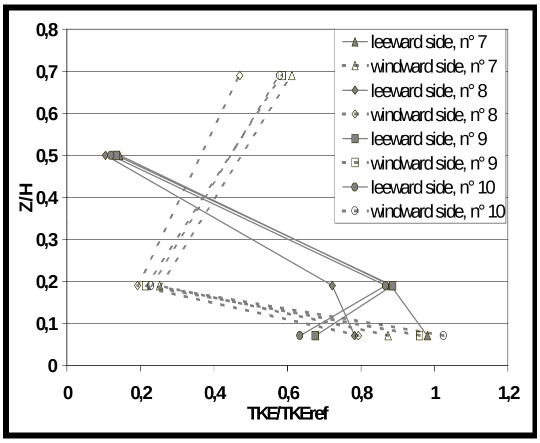

Figure 2.2 Turbulent kinetic energy within the street, the 24th and 25th of June 1999

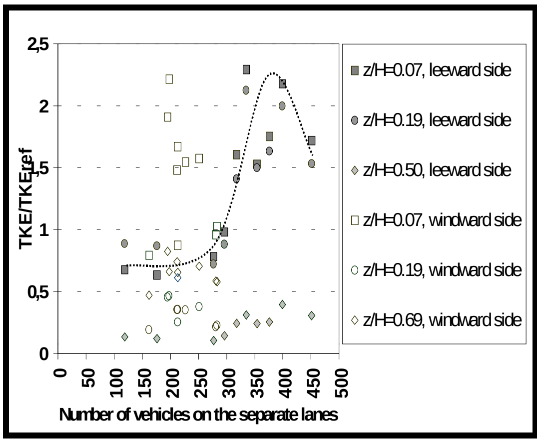

Figure 2.3 Dependence of the turbulent kinetic energy on the number of vehicles

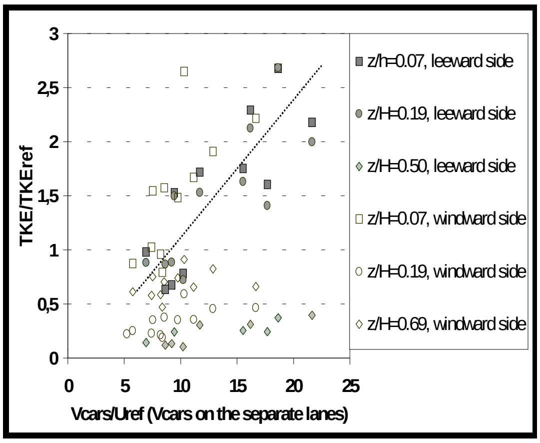

Figure 2.4 Dependence of the turbulent kinetic energy on the vehicle velocity

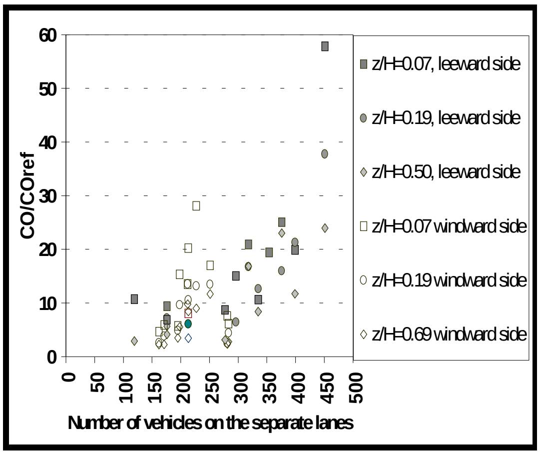

Figure 2.5 Dependence of CO concentration on the number of vehicles

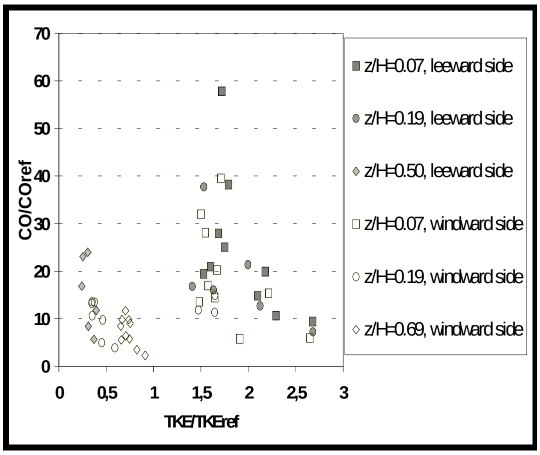

Figure 2.6 Dependence of CO concentration on the turbulent kinetic energy