A FIELD EXPERIMENTAL WORK ON THE TURBULENT CONCENTRATION FLUCTUATION OF ATMOSPHERIC CONTAMINANTS IN THE VICINITY OF A BUILDING

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Abstract: *This work investigates the turbulent flow and dispersion of atmospheric contaminants in the vicinity of an isolated building. Field experiments were carried out to measure the concentration fluctuations on the surfaces of a complex shaped building, and to investigate the influence of atmospheric stability on the concentration distribution on the surface of such a building. The experiments were performed in flat terrain with uncut vegetation using a rectangular shaped building. Meteorological conditions varied from stable to unstable. The tracer gas used was propylene, which was released from a continuous source located 15 meters upwind and at half building height. The measurements were conducted for two different building orientations in relation to the wind direction. The detectors used were PID (Photo Ionisation Detector), with a response time of approximately 1/50 seconds, which is short enough to supply data of high frequency concentration fluctuation. There were 16 detectors located on the building walls. This paper also presents the turbulence statistics of the flow, which enabled to identify the meteorological condition. Thus, the three components of the wind flow and the speed of the sound in air were measured using ultrasonic anemometers located at three different vertical positions (1.5, 3.0 and 6.0 m), at a frequency of 20 Hz. The speed of the sound in air was measured in order to supply temperature and turbulent heat flux data. Statistical parameters of the concentration and the wind flow are presented, including mean and standard deviation. Intermittency and concentration fluctuation intensity are also presented. Results were analysed based on the turbulent structures of the fluid flow around the building. The experimental work revealed that a variation from neutral to unstable atmospheric conditions influenced significantly the concentration levels on the external walls of the building, except on the windward wall. It was also revealed that mean conditional concentration values on the walls were significantly influenced by the building orientation in relation to the wind direction. Increasing the averaging time produced a slight decrease in mean concentration and a slight increase in concentration fluctuation intensity, especially on the leeward wall. This trend was most pronounced under unstable conditions.*

Keywords: *field experiments, building effects, concentration fluctuation*

1. Introduction

The presence of a building profoundly alters the atmospheric turbulent flow structure. The building not only disturbs the mean wind field, but also increases the turbulence nearby by generating a large amount of shear stress in the flow. These effects considerably modify the pattern of pollutant dispersion locally. The wind flow approaching the building depends on the atmospheric conditions, since the velocity and temperature profile and turbulent properties are determined by the prevailing stability conditions. The atmospheric stability conditions can assist or suppress the vertical turbulent transport according to the density stratification (buoyancy forces). These atmospheric conditions can vary from a strongly unstable atmosphere with a deep mixed boundary layer that promotes the contaminant spreading, to a stably stratified boundary layer that damps the vertical mixing of contaminants. Thus, in order to understand the atmospheric flow and dispersion around a building, it is necessary to include the effects of atmospheric stability.

Although there is a considerable amount of work in the literature about atmospheric flow and dispersion around buildings, among others Ogawa *et al* (1983), Jones and Griffiths (1984), Saathoff *et al*. (1995) and Smith et al. (2001), comparatively little work has been concerned with investigations under different stratified conditions. In fact, there is little field experimental work, no wind tunnel experiments and no numerical simulations of the atmospheric flow under unstable stratification with an obstacle present. This is due to the fact that only recently have wind tunnel facilities extended their capabilities to enable the simulation of the unstable atmosphere, and so there are as yet no reported wind tunnel investigations on the fluid flow around a building with an unstable stratification.

Thus, the majority of the studies investigating the effects of atmospheric stratification on the flow and dispersion around building is concerned with neutral and stably stratified conditions (Higson et al., 1994 and Higson et al., 1996). Only very recently, few works studying unstable conditions in the atmosphere have been reported in the literature, such as Mavroidis (1997) and Mavroidis et al. (1999), but these are mainly focussed on the dispersion around cubic shaped buildings. This work extends the previous studies, by investigating the turbulent flow and dispersion of atmospheric contaminants in the vicinity of an isolated complex shaped building. Field experiments were carried out to measure the concentration fluctuations on the surfaces of a complex shaped building, and to investigate the influence of atmospheric stability on the concentration distribution on the surface of such a building.

The main aim of the experiments is to investigate the influence of the unstable stratification of the atmosphere on the air flow and dispersion around a complex shaped building. This analysis is carried out by measuring the mean and fluctuation intensity of concentrations on the surface of the building under different atmospheric stability conditions for different building/source orientations relative to the wind and for different averaging time in the calculation of the mean concentrations.

The building/source orientations relative to the wind direction can influence the fluid flow more strongly around the obstacle since a wider obstacle affects the atmospheric flow and causes the contaminants to be more dispersed. The concentration levels seen on the walls of the building can be strongly affected by the wind direction.

2. Experimental Details

Field experiments were conducted at Dugway Proving Ground, 85 miles south west of Salt Lake City in Utah, USA. The experiments were conducted during August 1998 at different times of the day (including nighttime) in order to collect data for different stability conditions. This region reliably experiences unstable atmospheric conditions during the daytime and stable conditions at nighttime.

The experiments involved placing a source of propylene gas at a fixed distance from the building and using gas detectors (Photo-Ionisation Detectors – PID's) to measure concentration close to the walls and on the roof of the building. Figure 1 presents a view of the building used in the trials and shows a schematic representation of the site, indicating the location of the source of gas and PID's. The source was located upwind at a distance of about 3.5 building heights (x=3.5 Hb) from the face of the building, at a height of 0.5Hb. The source released propylene gas though an open-ended pipe of about 1 cm in diameter with a flow rate of 50 litres per minute.

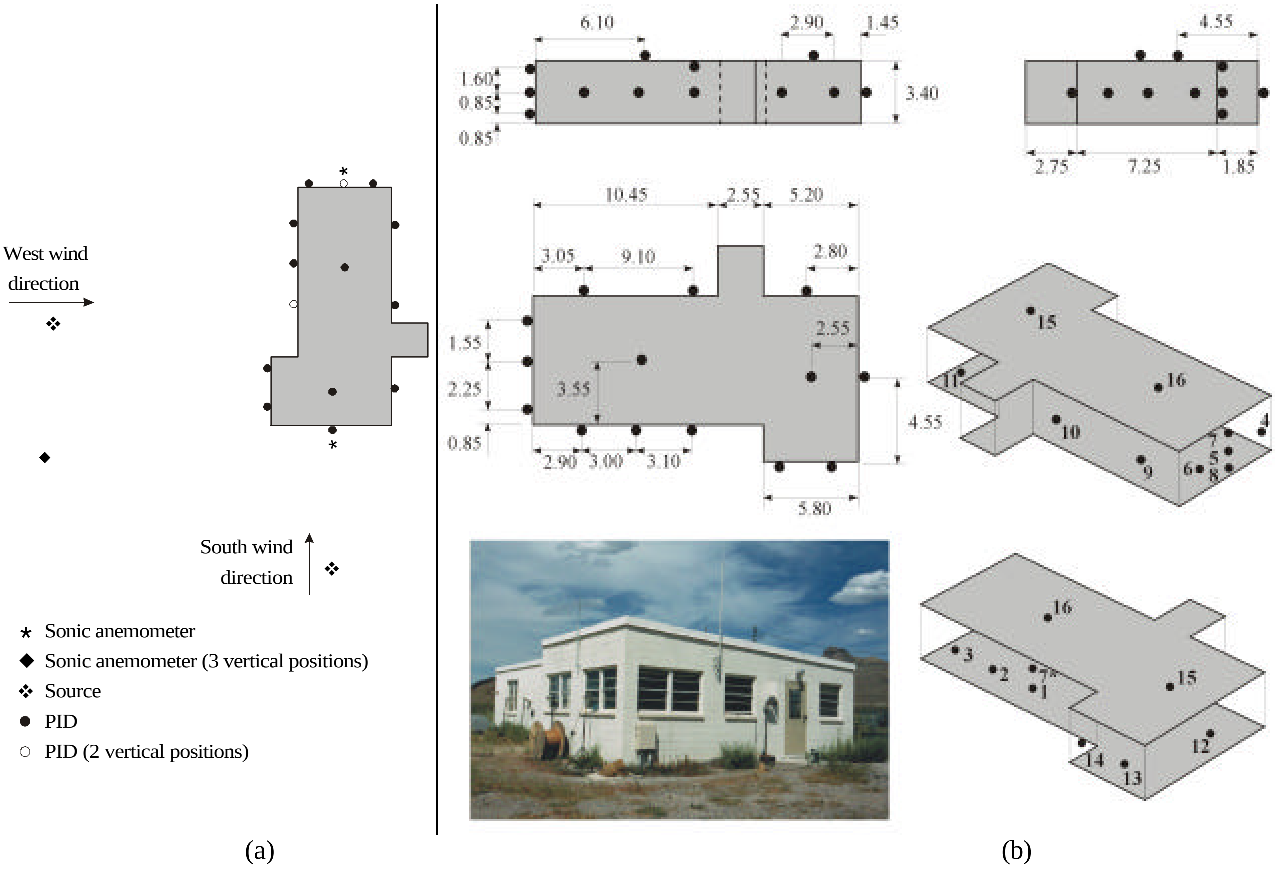


Figure 1 – (a) Schematic representation of the site, (b) the building used in the experiments at Dugway Proving Ground (view looking from SSW) and a schematic representation of the sensor locations on the building surfaces.

The terrain where the experiments were conducted is flat for many kilometres on the west and south side of the building and with some hills at about 1 to 2 km to the east and north. In order to avoid the influence of these hills on the wind profile, the experiments were conducted only when the wind was blowing from the west and south side of the building to guarantee that the wind profile was similar to a boundary layer flow. The vegetation is low patchy grass (maximum 15 cm) and the terrain roughness is about 10 mm calculated from the velocity profile in neutral stability.

2.1. Gas Monitoring and Method of Analysis

Concentration measurements were made by sampling using a number of digital fast-response photo-ionisation detectors (PID's) of the type shown in figure 2a and 2b (made by Aurora Scientific Inc.). This instrument has a response time corresponding to about 50 Hz. It samples the ambient air at a flow rate of 1 l/min and this sample is exposed to a high energy ultra-violet light, which ionises the tracer gas. Molecules having ionisation energy levels below the lamp photon energy are ionised. At low concentrations (in the range up to approximately 800 ppm) the instrument response is linearly proportional to the concentration of the contaminant gas. The ions formed are collected on an electrode system providing an electrical field, producing an ion current that is proportional to tracer gas concentration. The ion current is amplified and converted to a voltage signal whose value is proportional to the gas concentration.

The detectors and the source were located at half building height, i.e. $y = Hb/2$, except sensors 15 and 16, which were located on the roof and sensors 7 and 8 located at the top (y = 0.97 Hb) and the bottom (y=0.25 Hb) of the wall, respectively (Fig. 1b).

By applying the baseline correction (in which the slowly-varying baseline signal was removed from the data) and the calibration curves of the instruments (using calibration measurements conducted during the trials), the voltage signals recorded by the acquisition system were converted to concentration values (ppm). This data conversion produced time series of concentration for an averaging time of 1 second to reduce the file sizes.

$$\overline{C} = \frac{1}{N}\sum_{n=1}^{N} C_n \tag{1}$$

where C_n is the concentration at the nth observation and N is the number of observations. The number of observations N is determined by the averaging time used for the analysis of each set of data.

(a) (b) (c)

Figure 2 – (a) Lateral and (b) frontal views of a PID detector, manufactured by Aurora Scientific Inc. (c) The ultra-sonic anemometer sensor system.

The 50Hz data were not required for this study, since the investigation is more concerned with longer averaging times (1 sec or more). Those 1 second averaged data still contain information about fluctuations of concentration due to turbulent eddies. Thus, the deviation of the measured values in relation to the mean (standard deviation -σ_c^2) represents turbulent concentration fluctuations, calculated as

$$s_c^2 = \frac{1}{N}\sum_{n=1}^{N}\left(C_n - \overline{C}\right)^2 \tag{2}$$

In order to obtain information from the data about turbulent fluctuations, it is important to analyse concentration fluctuation values in relation to the levels of the mean concentration, since a certain absolute value of fluctuation can represent a large relative fluctuation if the mean value is low or a small relative fluctuation if the mean is high. Thus, the standard deviation is normalised by the mean concentration and presented in terms of the coefficient of variation or the concentration fluctuation intensity, which is defined as

$$i = \frac{s_C}{\overline{C}} \tag{3}$$

A detector will experience periods of zero concentration due to pockets of clean air brought into the plume by the small-scale atmospheric turbulence and due to the large-scales of turbulence that will cause the plume to meander. The term intermittency is used to describe this characteristic of the concentration time series. Although this characteristic appears at first a simple idea, the literature contains several definitions of intermittency. Chatwin and Sullivan (1989) discussed this topic and proposed a definition that was suitable for both theoretical and practical applications. Here, for consistency with the work of Higson (1995), to enable the same basis of comparison, the definition adopted is that the intermittency, I, is the proportion of time for which the concentration is at or below a threshold value, which in this case is the nominal zero concentration.

(p p m)

It is important to determine the nature of the concentration distribution within a plume by excluding the periods of zero concentration. Thus, conditional statistics are used in this work to represent the mean concentration that excludes the periods of zero concentration ($\overline{C}_{cond}$). It is calculated in the same way as the complete mean concentration presented in equation 1, except that the observations when the concentration is at or below a threshold value are not included. Higson (1995) pointed out that the concepts of intermittency and conditional statistics have been developed in the context of a plume dispersing in open terrain. However, they may be applied to studies of dispersion around obstacles. The relation between the conditional mean concentration and intermittency (*I*) can be written as

$$I = \frac{\overline{C}_{cond} - \overline{C}}{\overline{C}_{cond}} \tag{4}$$

Another important parameter is the cumulative frequency, which represents the cumulative density function (cdf) of concentration of a time series. The cdf gives the proportion of concentration readings which are below a given concentration (expressed as the ratio between the instantaneous and mean concentration values), and provides the following information: (a) the concentration fluctuation intensity which can be seen from the slope of the central part of the curve (the lower the intensity the steeper the gradient); (b) intermittency which is indicated by the point where the curve crosses the vertical axis; and (c) the ratio between peak and mean obtained from the value where the cdf reaches 1. Figure 3 presents two examples of time series of concentration and the corresponding cumulative density function from the Dugway experiments. Note that *I*=0 for both of these examples.

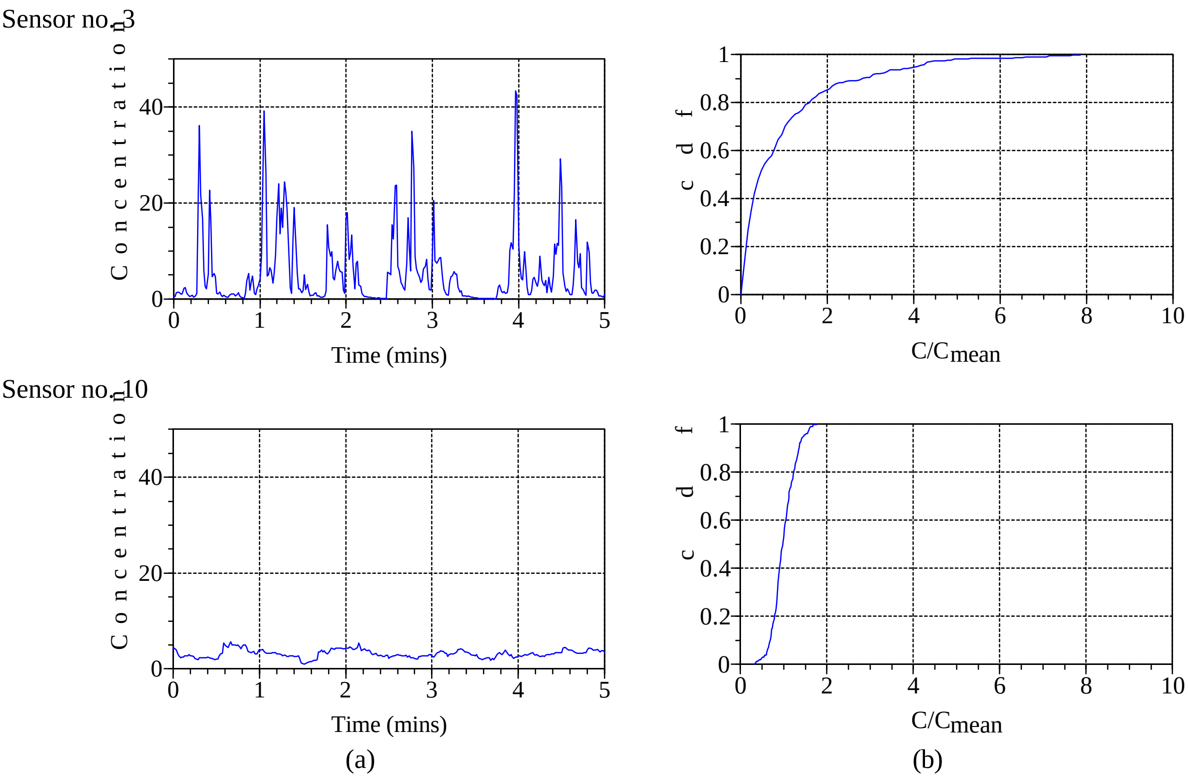


Figure 3 – Examples of (a) time series and (b) cdf's for two different positions around the obstacle.

2.2. Meteorological Instrumentation and Method of Analysis

Meteorological data were acquired using three ultrasonic anemometers located in a vertical array (y = 0.44Hb, 0.88 Hb and 1.76Hb) at a distance of 30 m west of the building (figure 1a). These instruments provided three orthogonal components of velocity vector of the wind and the speed of sound in air at a frequency of 21Hz. The ultrasonic anemometers (figure 2c) operate as three pairs of transducers that alternately send and receive high frequency ultrasound pulses.

The speed of sound is related to the air temperature. Thus, by measuring the speed of sound and using the relation proposed by Weast (1971), the temperature can be calculated as

$$T = 273.16\left(\left(\frac{v_{sound}}{331.5}\right)^{2} - 1\right) \tag{5}$$

where T is temperature in Kelvin and v_{sound} is the speed of sound in metres per second (331.5 ms-1 for dry air at 273.16K).

By using the wind velocity and temperature, it is possible to determine the values of friction velocity ($\sqrt{-\overline{w'v'}}$), sensible heat flux ($c_p r \overline{v'T'}$), standard deviation of the horizontal and vertical wind direction (σ_θ and σ_θ), Monin-Obukov length and Richardson number. The sensible heat and the flux friction velocity were calculated directly from the covariance of the fluctuating vertical velocity and temperature and the covariance of the fluctuating longitudinal and vertical velocities, respectively.

The ultrasonic anemometer measurements were complemented by measurements of ambient pressure, humidity and temperature provided by a meteorological station located within 500 m of the building.

2.3. Averaging Time

The averaging time was chosen based on a time scale of turbulence in the near-wake of the obstacle, which is of the order of Hb/W_{Hb} (where Hb is the building height and W_{Hb} is the wind speed at one building height). This time scale is about 1 second for these experiments, since the wind speed is higher than 2.5 m/s. As Mavroidis (1997) indicates, the averaging time needs to be hundreds of times larger than the time scale of the flow around the obstacle. Thus, the time series of 1 second averaged data are averaged over a number of periods of 5 minutes (except where stated otherwise). The periods of 5 minutes selected for analysis were chosen from episodes when the mean wind direction (averaged over the 5 minute period) was normal to the building wall within ±10 degrees and the wind speed was greater than 2 m/s.

Over the period of the campaign, 14 experiments were carried out. The data periods selected for analysis are set out in table 7.2. Ten basic episodes were selected on the criterion that the wind direction was approximately perpendicular to the windward face of the building (within 10 degrees of the expected wind direction) over the period of the episode. On this basis three episodes of 30 minutes duration and seven episodes of 5 minutes duration were chosen. Six additional episodes (three of 3 minutes and three of 10 minutes) were extracted as subsets of the 30 minute episodes. The atmospheric stability conditions for these episodes varied from neutral to unstable and the wind speed was higher than 2.5 m/s.

3. Results and Discussion

This section presents the results obtained from the field experiments conducted. The main aim of the experiments is to measure the concentration distribution on the surfaces of a complex shaped building and to investigate the influence of the unstable stratification of the atmosphere on the air stream and dispersion around a complex shaped building.

The analysis is carried out in two sub-sections that describe, respectively, the influence on concentrations of the building/source orientations relative to the wind direction, and the atmospheric stability. The meteorological data for the chosen scenarios are shown in table 1.

Table 7.2 – Meteorological data.

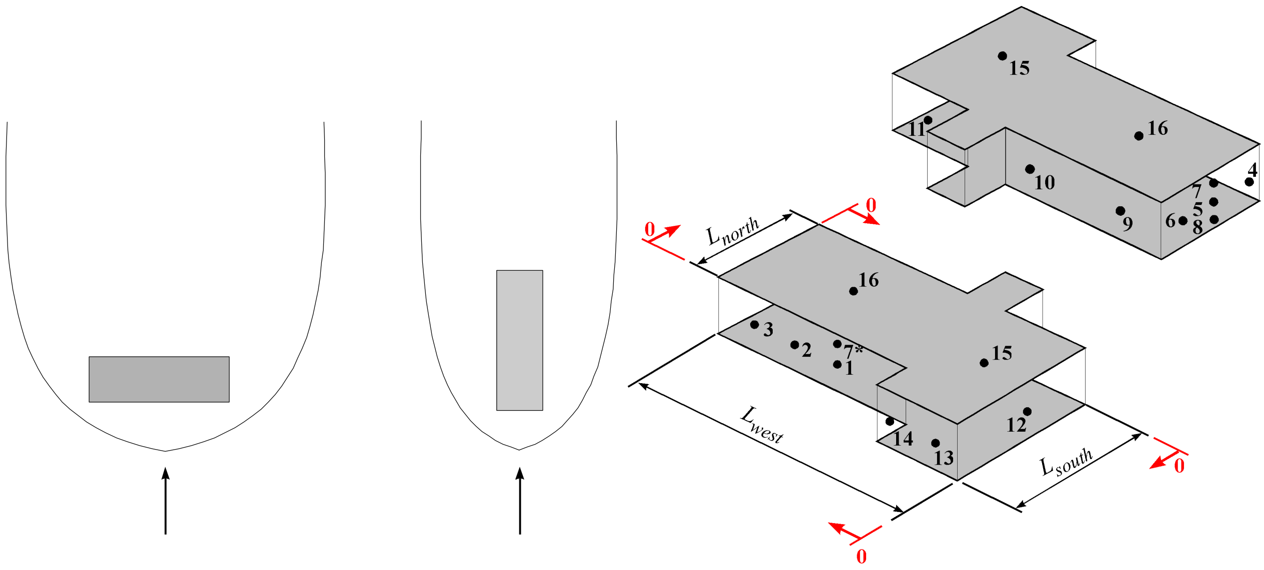
Exp.	Wind dir./ stability	Avg. time (min)	Speed (m/s)	θ (deg)	s_q	L (m)	u_* (m/s)	Ri_{flux}	$\overline{T}$ (°C)	TKE* (m^2/s^2)
1	South wind/Neutral	5	6.15	180.7	8.30	-50.84	0.57	-5.90×10^{-2}	41.25	1.38
2	South wind/Neutral	5	5.31	182.4	12.33	-54.14	0.54	-5.54×10^{-2}	41.54	1.53
3	West wind/Unstable	5	4.42	263.2	16.17	-13.06	0.37	-2.30×10^{-1}	40.15	1.67
4	West wind/Unstable	5	2.48	265.1	21.38	-0.98	0.15	$-3.07\times10^{+0}$	40.36	1.28
5	West wind/Unstable	5	2.86	264.4	16.78	-14.31	0.33	-2.10×10^{-1}	42.03	1.16
6	West wind/Neutral	5	4.61	267.1	14.53	-24.87	0.47	-1.21×10^{-1}	42.90	1.41
7	West wind/Neutral	5	2.79	261.4	17.42	-43.69	0.54	-6.87×10^{-2}	42.10	1.43
8	South wind/Neutral	3	5.76	178.6	8.74	-66.63	0.62	-4.50×10^{-2}	41.61	1.51
9	West wind/Unstable	3	2.29	258.0	18.63	-5.93	0.26	-5.06×10^{-1}	40.16	0.94
10	West wind/Neutral	3	3.84	265.3	15.55	-53.64	0.58	-5.59×10^{-2}	42.79	2.10
8	South wind/Neutral	10	5.29	183.0	12.85	-39.17	0.50	-7.66×10^{-2}	41.17	1.81
9	West wind/Unstable	10	2.60	250.4	33.36	-5.29	0.26	-5.67×10^{-1}	40.39	2.45
10	West wind/Neutral	10	3.79	262.8	17.87	-46.85	0.53	-6.40×10^{-2}	42.72	2.20
8	South wind/Neutral	30	3.80	178.3	21.82	-46.82	0.47	-6.41×10^{-2}	41.11	2.58
9	West wind/Unstable	30	2.98	265.5	32.45	-8.84	0.31	-3.39×10^{-1}	40.13	2.48
10	West wind/Neutral	30	3.71	263.5	24.44	-36.43	0.50	-8.24×10^{-2}	42.33	3.74

* TKE represents the *Turbulent Kinetic Energy* of the incident flow

3.1. Concentration Distribution and the Influence of Building/Source Orientations Relative to the Wind

Initially, the concentration distribution measured in neutral conditions is analysed. Then, a comparison of concentration distribution on the building surface for two building/source orientations relative to the wind is presented. As stated earlier, experiments were carried out with two building/source orientations: wind impinging on the larger face of the building (west wind direction) and wind impinging on the shorter face of the building (south direction), as shown schematically in figure 4a. In the first configuration, the ratio between the building width and height (*Lwest/Hb*) is 5.35 and in the second configuration this ratio (*Lsouth/Hb*) is 1.34, where *Lwest* and *Lsouth* denotes the length of the west and south faces the building, respectively (figure 4b).

Figures 5a and 5b present the normalised mean concentration on the building surfaces for sources located upwind of the centre of the long face (west wind direction) and short face (south wind direction) of the building, respectively, from two runs each. For the west wind direction, run A represents experiment no. 7 and run B represents experiment no. 6. For the south wind direction, run A represents experiment no. 2 and run B represents experiment no. 1 (table 1). Both figures show that there is a maximum value for the central sensor on the windward wall and that the mean concentration decreases when the distance from the central position increases. The mean values of concentration on the leeward wall are nearly constant and comparable to the minimum values measured on the windward wall. The mean concentration on the lateral walls is also lower and nearly constant. These regions are characterised by a boundary layer separation (leeward and lateral walls), where there are high levels of turbulent kinetic energy and low velocities, which produce well-mixed regions. It is clear from figure 5b that the values of concentration on the right wall are neither homogeneous nor similar to those on the left wall, which is due to the lack of symmetry and complex building geometry.



(a) (b)

Figure 4 – (a) Schematic representation of the regions around the obstacle in which the flow is influenced by the building presence in the case of wider and longer obstacle. (b) Schematic representation of the lengths *Lwest, Lnorth, Lsouth*.

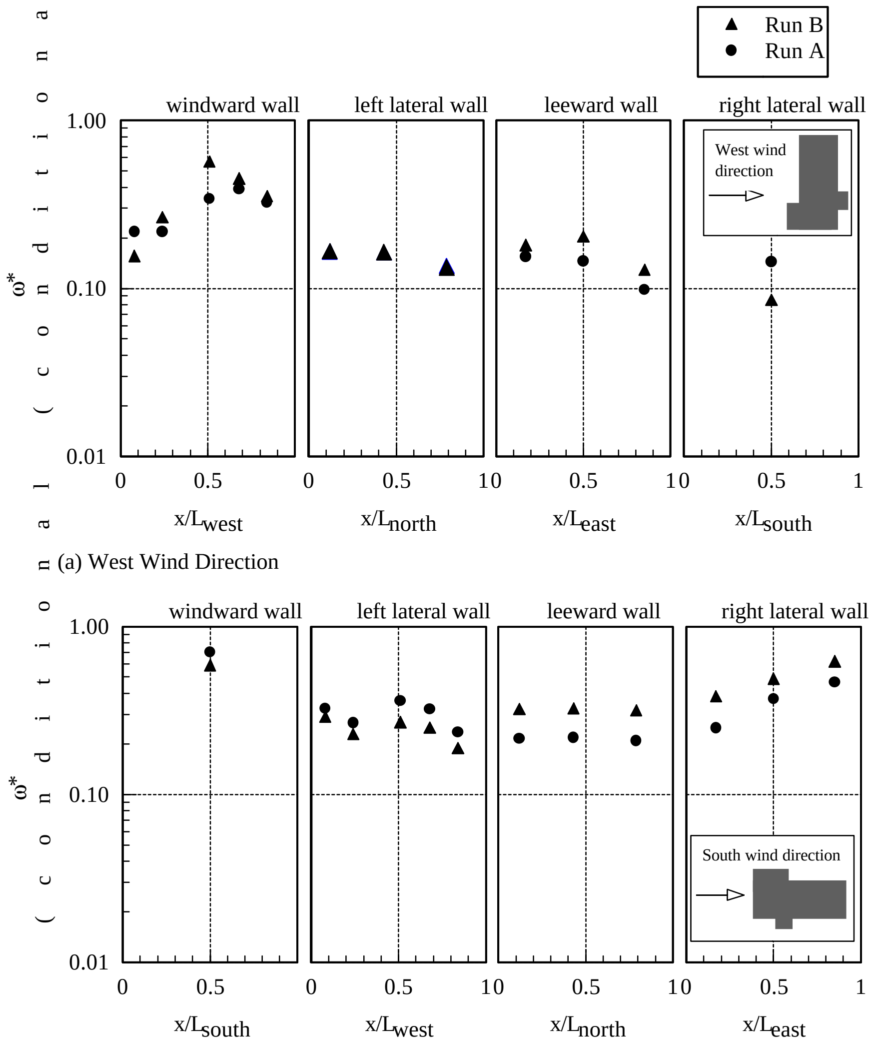
The source is located close to the building (x = 3.5Hb) for both source/building orientations, thus the plume dimension reaching the obstacle is less than or comparable to the building width. There is a clear indication from the experimental data that, in general, the means are higher for the plume reaching the shortest wall (figure 5b). The region of the flow disturbed by the building is smaller when the flow is impinging on the shortest wall, thus the plume is less spread and higher concentration values occur.

Figures 6a and 6b show that the concentration fluctuation intensity is nearly uniform on each of the building walls, except on the right corner of the windward wall due to the complex and asymmetric shape of the building. These figures also indicate that the distributions of concentration fluctuation on the windward, leeward and lateral walls are comparable for both building/source orientations in relation to the wind direction. It is important to note here that large values of fluctuation intensity are related to the large scale turbulent motion and small values are associated with the small scale turbulent motion.

In order to evaluate the influence of the building shape, the results presented here are compared with field experimental data obtained by Higson et al (1996). Both experimental investigations used complex, but not identical, shaped buildings. Therefore, a comparison between these two sets of data can indicate the influence of changes in building shape on the distribution of concentration on the obstacle surface.

Higson et al (1996) carried out experimental investigations at Altcar Rifle Range (England) on dispersion around an isolated obstacle with an L-shaped "penthouse" added on the roof. The building dimensions are similar to those of the building used in the work presented here. A tracer gas was released upwind of the building (x = 4.07Hb and 12.20Hb)

and concentration measured using a detector system with response time of approximately 1s. The experiments were undertaken under neutral atmospheric stability conditions paying attention to the fluctuation components of concentration for the purpose of comparing the concentration distribution measured in the field with those measured in experiments conducted in a wind tunnel. The analysis presented here includes only comparisons with the field experiments carried out by Higson et al.



(b) South Wind Direction

Figure 5 – Mean concentration in neutral conditions for source located upwind of the centre of (a) the long face of the building and (b) short face of the building. The two different symbols represent two periods of 5 minutes in similar meteorological conditions.

There is a similarity between the results obtained in the field experiments carried out by Higson et al (1996) and those reported here, which can be seen in figures 6a and 6b. The fluctuation intensity values obtained in this work are higher than those obtained by Higson et al. (1996), except on the leeward wall where the values are comparable. In fact, there are more similarities in the case with the wind impinging on the smaller wall; the levels of fluctuation intensities are quite similar in this case. This is possibly related to the different type and location of the features of the building.

Figures 7 and 8 present the function of cumulative frequency on the right, which represents the cumulative density function (cdf) of concentration, for different sensors, and the corresponding time series (on the left). The cdf gives the proportion of concentration readings which are below a given concentration (expressed as the ratio between the 1 sec averaged and mean concentration values). These figures also show two different runs (A and B) to illustrate the representativeness of the sample selected. It can be seen that the results are almost identical.

It is clear from figure 7 that the sensors no. 1 and 3 have similar cdf shapes. These cdf's show a different shape when compared to the cdf for the sensor no. 10 (located on the leeward wall). In this location, the concentration fluctuation intensity and the peak divided by the mean are lower due to lower velocities and high levels of turbulent kinetic energy in the region downwind of the obstacle (in comparison with the free upstream flow).

It is important to remember that the data presented here were selected according to the wind direction (± 10 degrees) and the wind speed (> 2 m/s). Therefore, the intermittency of the concentration data is related to the meandering due to the large scale of turbulence rather than to the meandering due to the changing direction of the mean wind.

The cdf's obtained for the two different building orientations (figures 7 and 8) analysed are quite similar despite the fact that the mean concentration is higher for the case where the narrowest wall faces the wind. The time series presented shows clearly that the turbulence scales on the windward and leeward walls do not vary according to the building/source orientation, which implies that the concentration fluctuation intensity on the building surface is more influenced by the building height than by the width. Thus, it is possible to say that the building height is the characteristic dimension, which determines the dominant size of the scales of turbulent eddies close to the obstacle.

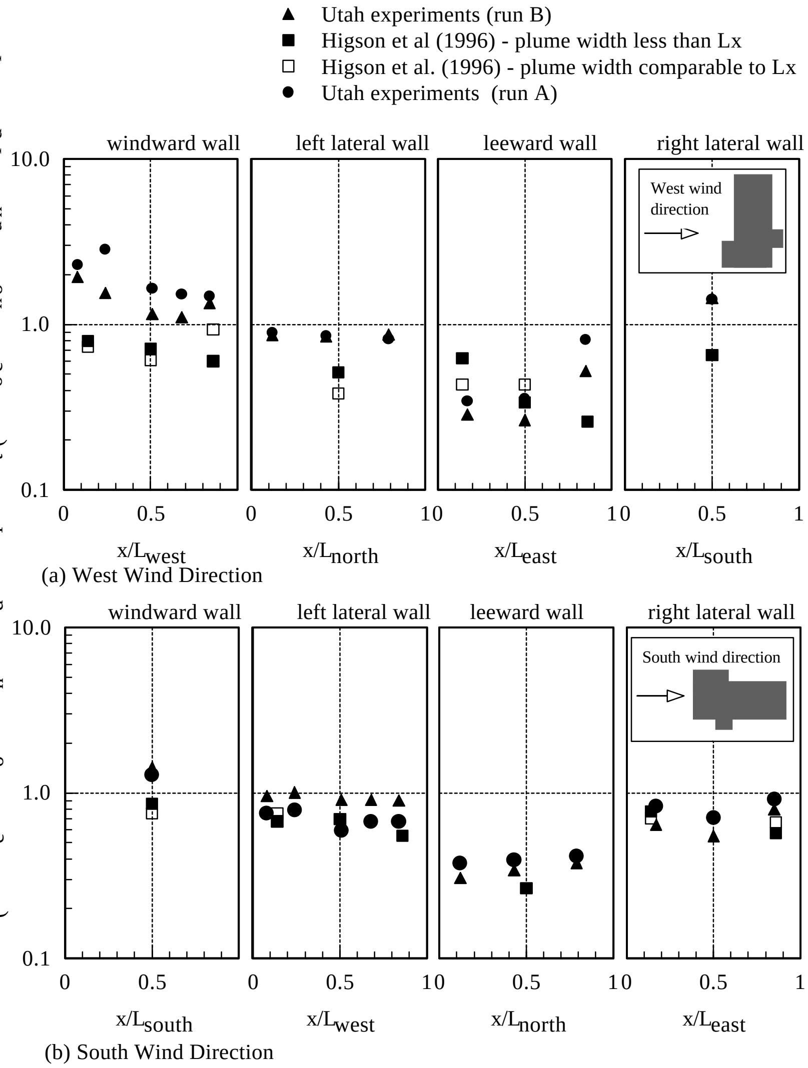


Figure 6 – Concentration fluctuation intensity in neutral conditions for a source located upwind of the centre of (a) the long face of the building and (b) the short face of the building. The two different symbols represent two periods of 5 minutes in similar meteorological conditions.

The dashed lines in figures 7 and 8 represent the cdf's obtained by the field experiments carried out by Higson et al. (1996). Despite the concentration fluctuation intensity presented by Higson et al. being, for all sensors, lower than those reported here, the shapes of the cdf's shown in figures 7 and 8 are similar for both field experiments. This can be understood to mean that the characteristic behaviour of dispersion on the different surfaces of the obstacle (windward face, leeward face, and so on) was not strongly influenced by the slightly different building shape in the two experiments.

3.2. Atmospheric Stability

MacDonald (1997) suggests that in the near field of an obstacle, the thermal stratification of the flow does not significantly affect the dispersion of contaminants, since mechanical turbulence generated by the obstacle tends to overcome any stratification effect. However, according to Robins (1994), in strongly convective conditions, the high levels of atmospheric turbulence quickly overcome the flow and dispersion features generated in the vicinity of an obstacle. Moreover, in strongly stable conditions ($Fr \leq 2.5$), the reattachment of the flow on the top and lateral sides of the building is enhanced and that dramatically changes the concentration field (Snyder, 1994). Thus, it seems that there is a range of atmospheric conditions about the neutral conditions outside of which the vertical structure of temperature affects significantly the dispersion of contaminants in the vicinity of the obstacle.

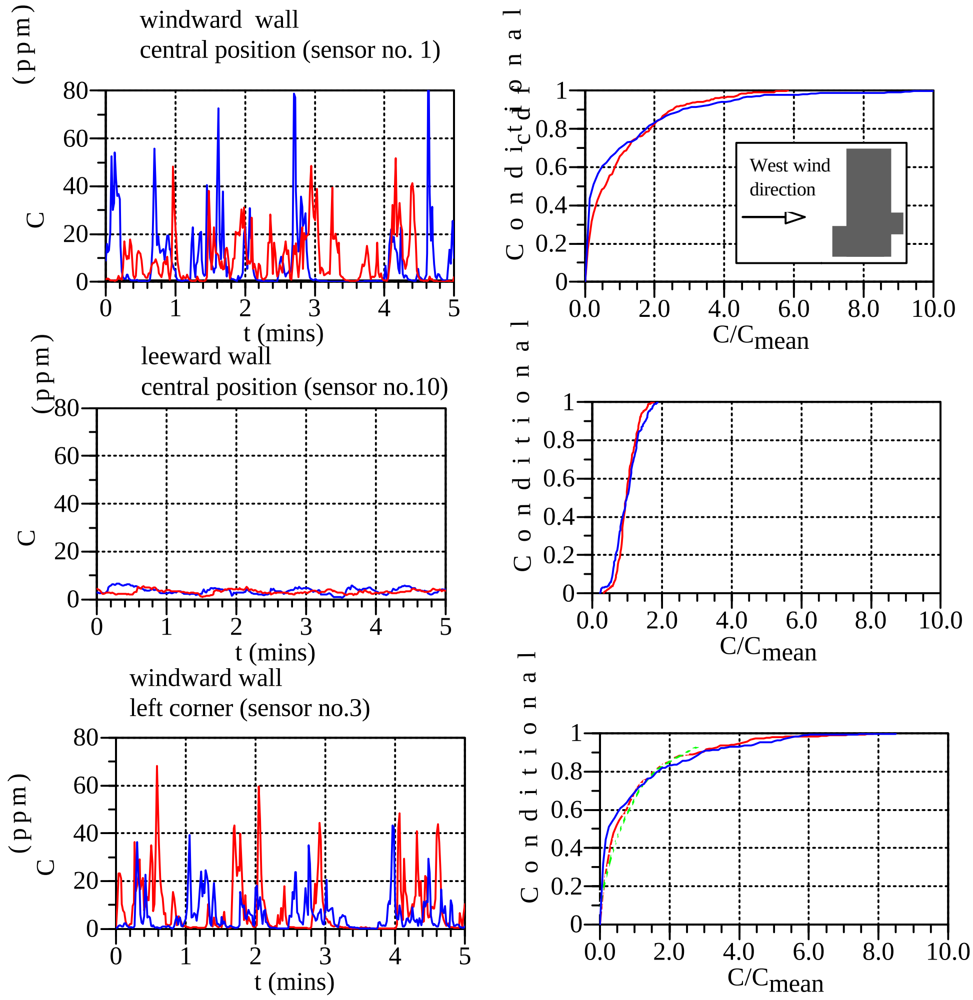


Figure 7 – Time series and conditional cdf's in neutral condition for source located upwind of the centre of the long face of the building. The two different experiments (run A and run B) represent two periods of 5 minutes in similar meteorological conditions.

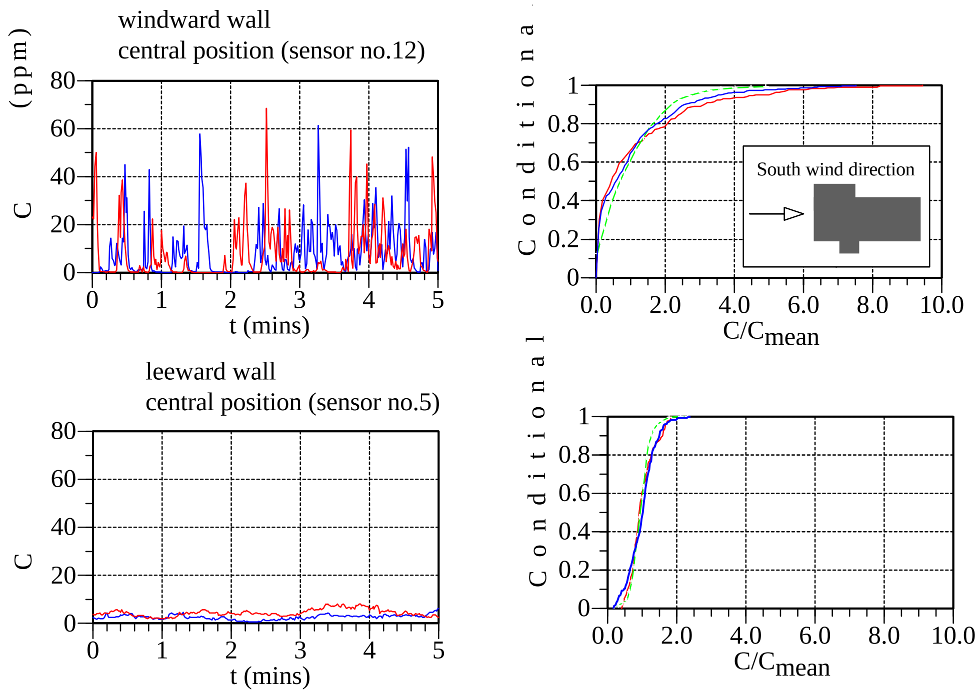


Figure 8 - Time series and conditional cdf's in neutral condition for source located upwind of the centre of the short face of the building. The two different experiments (run A and run B) represent two periods of 5 minutes in similar meteorological conditions.

The data presented in this section was selected by choosing 5 minutes periods from experiments no. 9 (30 minutes period with west wind direction and unstable conditions) and 10 (30 minute period with west wind direction and neutral conditions). These 5 minutes periods represent the time interval when the mean concentration for sensor no. 1 (in the centre of the windward wall) had its maximum value during the 30 minutes periods. Accordingly, these periods are expected to represent the intervals when the mean wind direction was closer to the direction perpendicular to the windward wall.

Strongly unstable or stable stratification tends to change the flow pattern around the obstacle from that under neutral stratification. For instance, increasing stability ($Fr \leq 3.0$) in the atmospheric boundary layer is associated with decreasing size of the recirculation region. This effect together with shorter plume spreading before impingement on the obstacle (the plume width decreases by a factor of 2 in relation to unstable atmospheric conditions) produces higher concentration levels on the building surface, as shown in figure 9. It is important to note that the plume width reaching the obstacle is comparable to or less than the building width.

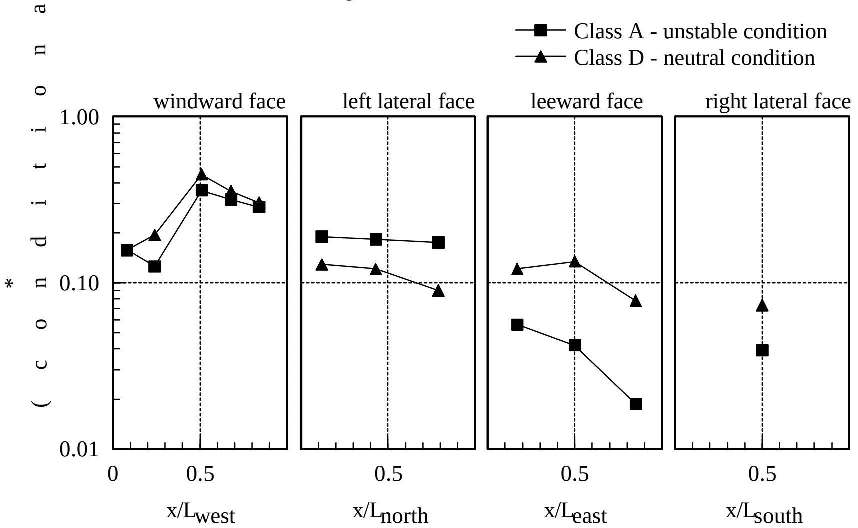


Figure 9 – Conditional mean concentration on the building surface for neutral and unstable atmospheric stability conditions.

This feature can not be observed on the left lateral wall, where the mean concentration values are higher under unstable condition. This behaviour is probably caused by the misalignment of the wind direction, since during the trials under unstable conditions, the mean wind direction was approximately 265 degrees as compared with 270 degrees, which corresponds to the direction normal to the building west face; while the mean wind direction during the trials under neutral conditions was approximately 267 degrees as compared with 270 degrees.

The concentration fluctuation intensity on the windward wall is not significantly influenced by the atmospheric conditions (figure 10). On the other hand, on the other walls the concentration fluctuation intensity is higher under unstable conditions, which is probably related to the larger separation region with larger turbulent eddies and higher turbulence levels.

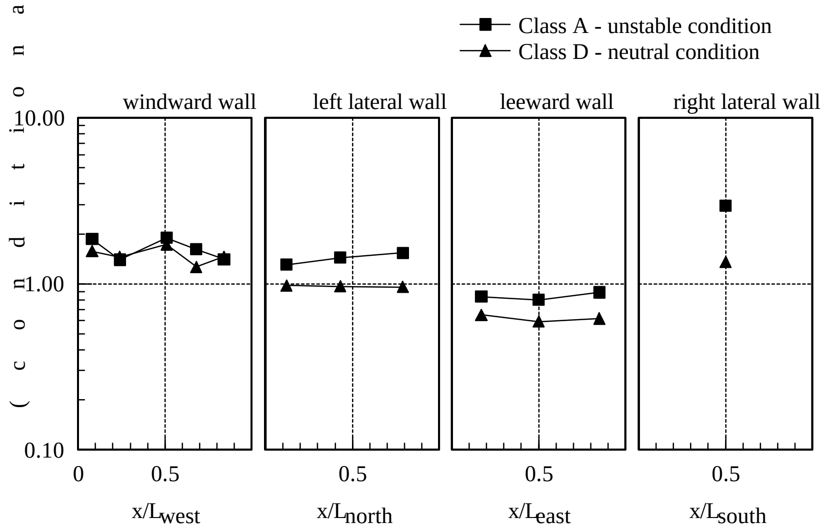


Figure 10 – Conditional concentration fluctuation intensity on the building surface for neutral and unstable atmospheric conditions.

Figure 11 shows the cdf's for different sensor positions on the building surface (sensors no. 1, 5, 10 and 12). In general the peak-to-mean values are higher for the measurements carried out under unstable conditions. This feature is more significant for sensors no. 5 and 12 (left and right lateral walls) probably because of the change in the level of turbulent kinetic energy on these walls for different stability conditions. On the windward wall the peak is about the same for both stability conditions analysed.

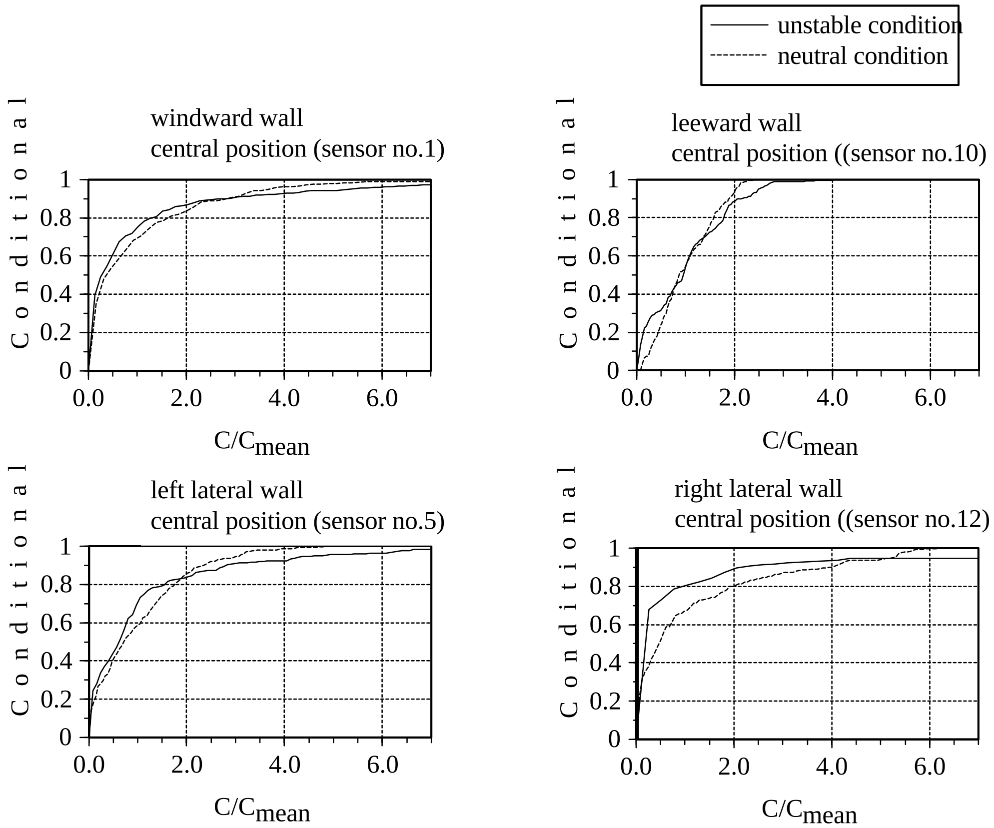


Figure 11 – Conditional cdf's on the building surface for neutral and unstable atmospheric conditions.

4. Conclusions

The experimental work carried out on the complex building revealed that the mean conditional concentration on the walls was significantly influenced by the building orientation in relation to the wind direction. There is a clear indication from the experimental data that: (1) the concentration on the windward wall is higher than on the other three walls; (2) the concentrations on all walls are higher when the shorter wall faces the wind. The region of the flow disturbed by the building is smaller when the flow is impinging on the shortest wall, thus the plume is less spread and higher concentration values occur. Concentration fluctuation intensity is nearly uniform on each of the building walls, and the distributions of concentration fluctuations on the windward, leeward and lateral walls are comparable for both building/source orientations in relation to the wind direction.

The changes in the fluid flow together with larger plume spreading before impingement on the obstacle produces lower mean concentration levels under unstable conditions. Concentration fluctuation intensity on the windward wall is not significantly influenced by atmospheric conditions, while on the other walls there are higher concentration fluctuation intensities under unstable conditions. The mean concentration values on the leeward wall were more affected by the changes in stability conditions than building orientation, while on the other walls this tendency was not repeated.

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