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A NEW DEVICE FOR TRACER GAS DISPERSION IN DUCTS FOR VERY SHORT MIXING DISTANCE

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ABSTRACT

The uniform tracer gas dispersion for very short distances, when measuring airflow by the constant emission method in HVAC systems is of great interest. In the present paper, the development of a new device for the injection of tracer gas is discussed with the objective of practical application in the field of air flow measurements. This injection device has a compact tubular shape, with magnetic fixation to be easy to apply to duct walls. One row of fifty-nine high speed micro jets in counter current direction, with the possibility of angular movement according to its main axle, makes the injection possible. A second separate device, with an effective integration function, feeds the sampling system for analysis. The device was tested in one special installation with a wind tunnel of approximately 21 m total length. The work section dimensions were 0.3m x 0.3 m. The distances between injection device and integration device considered were: X/Dh=22; X/Dh=4; X/Dh=2; and X/Dh=1. For the very short distances of X/Dh=2 and X/Dh=1, correction expressions were found, and a good repetition of air flow rate values was obtained. The final tests conducted demonstrated that the practical implementation of tracer gas techniques in HVAC systems, for measuring air flow rate with a very short mixing distance, is possible.

NOMENCLATURE

Dh - Duct hydraulic diameter [m]

x - Distance between injection and integration device [m]

Q_{xDh} - Duct Airflow for X/Dh=x [m^3/s]

$Corr_{xDh}$ - Correction for distance X/Dh=x

INTRODUCTION

Among "healthy building" concerns, the performance of ventilation systems plays an important role, therefore the accurate evaluation of building ventilation airflow has increasing interest. This type of measurement is important for the control of a good indoor air quality, but also for minimising energy consumption, [1-4]. In complex HVAC air systems, the measurement of airflow in difficult places and short duct sections (short length), increases difficulties of the conventional methods, specially because these are normally based on the scanning of the cross-sectional flow area, and depending on the complexity and asymmetries in the flow. With the future perspective of more accurate and compact analysers, with lower prices, tracer gas techniques have an increasing potential. Advantages of these techniques are known, specially the almost non-existent flow disturbance and independence of flow complexity, [5-6]. The major application difficulty is the necessary good mixture of the tracer gas with the main flow, [7]. This task is more difficult for very short duct lengths. The present work tries to solve some of these difficulties, creating a specially designed injection device.

EXPERIMENTAL SET-UP

The test facility consists basically in a specially calibrated wind tunnel allowing the different air flow rates of interest. The injection device was placed at the centre of the 15m work section. The calibration was carried with a Pitot tube, and the application of the log Tchebycheff method, [8-9]. This work implies the measurement of more than six thousand air velocities, scanning the 0.3m x 0.3m section area with a six by six matrix, for various flow rate values of practical interest. The tracer gas concentration was measured by using a photo-acoustic infra-red multi-gas analyser, made by INNOVA, model BK1312. Figure 1 represents the wind tunnel layout, with its main dimensions.

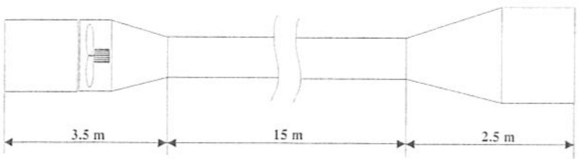

Figure 1 -Wind tunnel used in the experiments.

Figure 2 represents the complete injection circuit. Tracer gas flows from the pressurised bottle to the tracer doser, by a very sensitive low pressure regulator. One metering valve controls the mixture of the tracer with exterior carrier air. This mixture flows to the inlet of one piston compressor, which pressurises the mixture going to the injection device. Sulphur hexafluoride – SF_6, was the only tracer gas used in the tests.

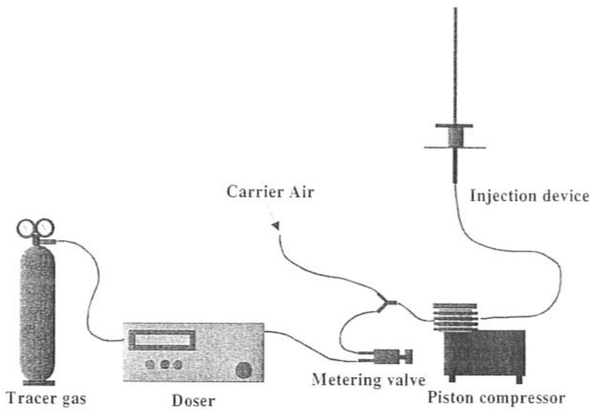

Figure 2 - Injection circuit used in the tests.

The integration device was placed in different locations, from X/Dh=22 to X/Dh=1, in a horizontal position (90º relatively to the injection device). Figure 3 represents the relative position of these two devices.

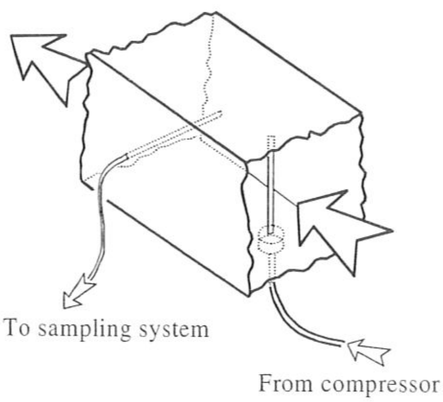

Figure 3 - Injection and integration devices - relative position.

The injection device (Figure 4), consists mainly of one 12.5mm tube with one row of fifty-nine precision 200 μm diameter holes, forming the tracer gas jets. These jets are fed by four hydraulic equilibrated circuits, for nearly the same pressure. The nominal length of this prototype is 0.3m. The injection device also has the capacity of axial angular scanning movement, with ninety degrees maximum aperture, manually adjustable (45º right /45º left). The scanning frequency can be varied with an electronic controller. This angular movement is more effective for tracer gas dispersion with lower air velocities, increasing the mixture with the main flow.

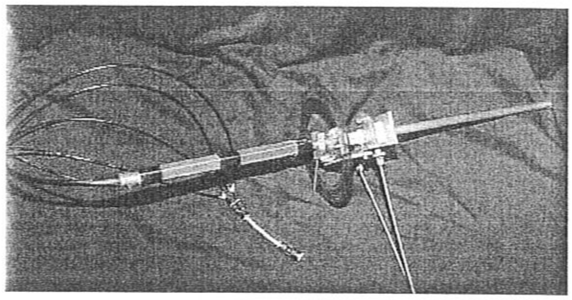

Figure 4 - The prototype injection device.

CFD STUDY AND SMOKE VISUALISATION

The CFD simulation was carried out with FLUENT 5.4.8 by using a k-ε turbulence model, for a simplified 2D geometry. The model consists of 51103 cells, representing one jet of 200 μm diameter and the surrounding area of the duct. Figure 5 represents the velocity field for an initial jet velocity of 300m/s. This particular boundary condition is similar to the real system tested and measured. The mean air velocity for the main flow is 2m/s.

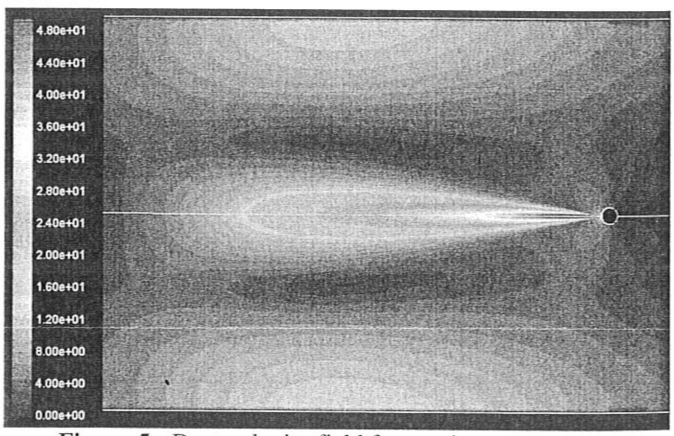

Figure 5 - Duct velocity field for one jet.

The smoke tests were carried out in a transparent section of the wind tunnel for various air velocities. Figures 6 and 7 represent flow visualisation at 3.2m/s. Figure 8 represents the free jets, in a section of the injection device. The smoke used has a density equal to of the air.

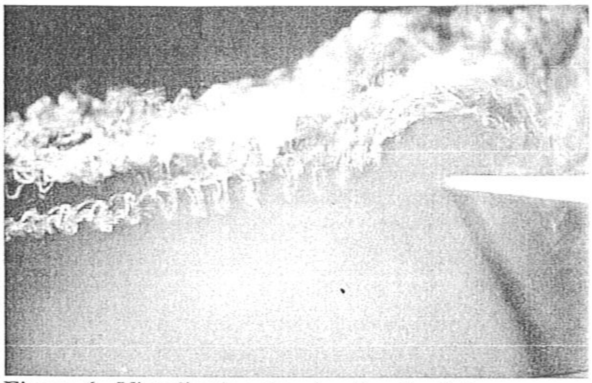

Figure 6 - Visualisation showing the circulation around the body of the injection device.

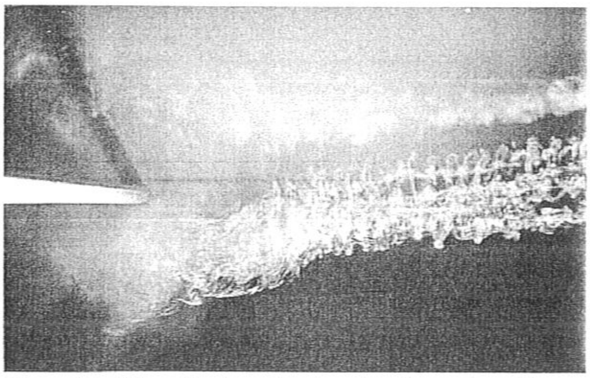

Figure 7 – Visualisation showing the dispersion effect of the jets.

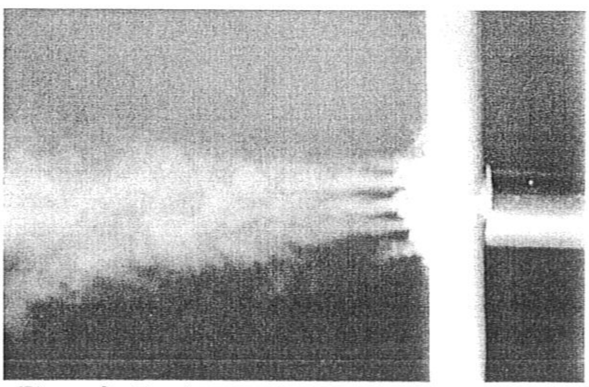

Figure 8 - Free jets (section of injection device).

The smoke is aspirated in a zone of strong depression, near the base of the jet, and the smoke is strongly accelerated. The diffuse aspect of the photograph is due to the jet high velocity. The special flash used, with a high illumination speed, was not capable of freezing the smoke movement. The body of the injection device has the diameter of 12.5mm, and it may serve as a scale reference. In conclusion, although we are comparing a three-dimensional and dynamic situation (experiment) with a static two-dimensional situation (CFD), it was concluded that a good agreement exists between experiment and CFD prediction.

WIND TUNNEL TESTS

Initially, long mixing distance measurements, with the integration device placed at X/Dh=22 were performed. Then, the distances of X/Dh=4, X/Dh=2 and X/Dh=1 were studied. The scanning axial rotation movement of the injection device was approximately 10Hz (10 scans in one second), and ninety degrees aperture (45° left / 45° right), counter current direction. Figure 9 represents the injection device in normal working position, during the tests.

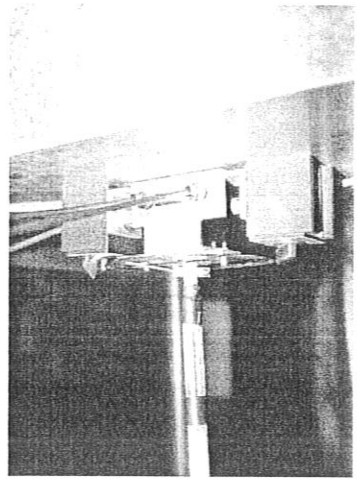

Figure 9 - Injection device during the experiments.

All the results are presented in graphical form, referred to the tunnel axial fan rotational speed. A scaled illustration showing the relative distances for the two relevant devices in normal position, is also presented for the extreme cases (Figures 10 and 11). The results for distance X/Dh=22 (Figure 12) are in good correlation with the reference Pitot tube measurements. For the lower flow rates measured, there is a little difference, possibly due to a lower turbulence, which is responsible for a good mixing.

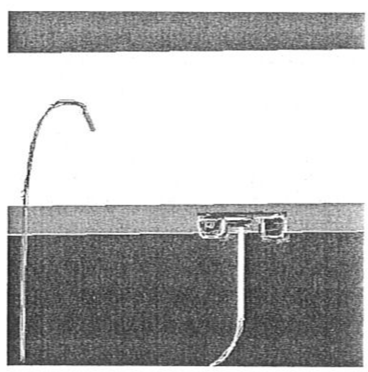

Figure 10 – Illustration for the relative position X/Dh=1.

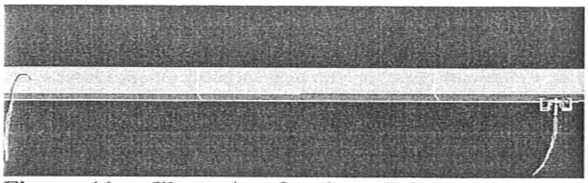

Figure 11 – Illustration for the relative position X/Dh=22.

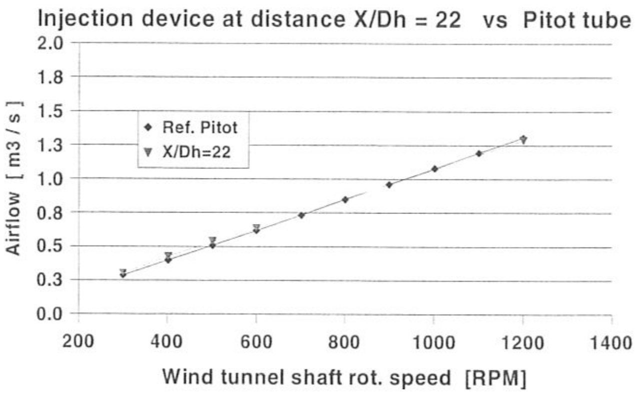

Figure 12 – Results for a distance X/Dh=22.

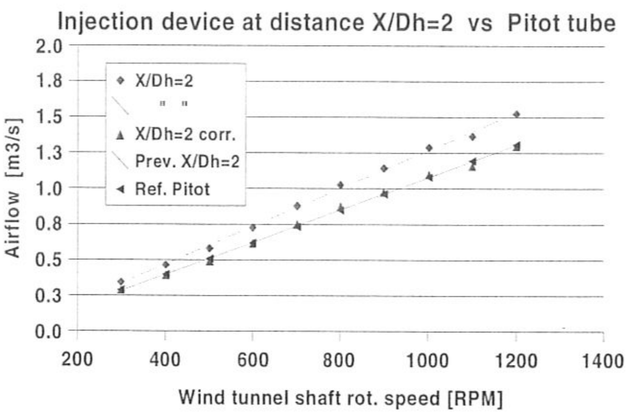

Figure 13 – Results for a distance X/Dh=2.

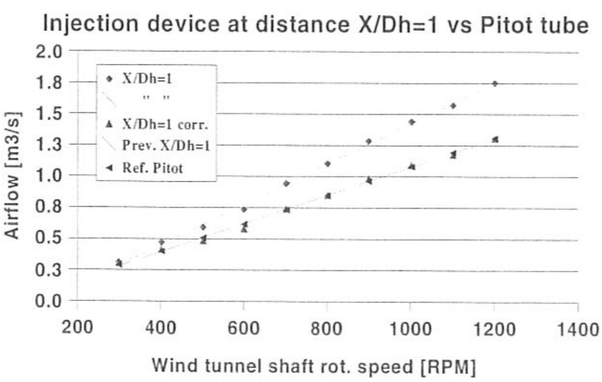

Figure 14 – Results for the distance X/Dh=1.

It is clear that for the very short distances of X/Dh=2 (Figure 13) and X/Dh=1 (Figure 14) a bypass effect is present. To overcome this effect, due to an incomplete tracer gas dilution, a simplified method of correction is proposed for these distances. Correction relations were established, using as a basis the reference Pitot tube measurements. The expression proposed for calculating the corrected values after the measured air flow rate values, has the following generic form:

$$Q_{xDhcorr} = Q_{xDh} - Corr_{xDh}$$

The correction expression for a distance X/Dh=1 is:

$$Corr_{1Dh} = 2.99\text{E-}1 * Q_{1Dh} \text{-}7.82\text{E-}2$$

The correction expression for a distance X/Dh=2 is:

$$Corr_{2Dh} = 1.44\text{E-}1 * Q_{2Dh} + 5.93\text{E-}3$$

The relative average deviation for these corrected air flow rate values, is 1.87% for X/Dh=2, and 2.57% for X/Dh=1. These values are acceptable, taking into account the difficulty of tracer gas dispersion for such short distances.

CONLUSIONS

The prototype injection device was tested in a sequence of experimental measurements. In this study, four different distances were considered, with practical interest for application in HVAC systems. The values obtained showed a good correlation with the reference Pitot tube measurements. For the very short distances of X/Dh=1 and X/Dh=2, simplified correction expressions have been found. This simple method is easy to apply in field measurements, producing accurate airflow values. For these extreme conditions, it is possible to implement the tracer gas technique and the constant emission method, with the help of the special injection device presented in this work.

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