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NATURAL VENTILATION DEVICE: A PRACTICAL USE FOR THE DEPRESSION IN A BLUFF BODY WAKE

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Abstract. *A new approach to promote natural ventilation in houses, buildings and industries is presented in this paper. In the device proposed in this work, the ventilation is caused by a pressure difference between the building interior (which is nearly equal to ambient pressure) and the base region of a bluff body, which, in the present case, is a flat plate kept normal to the wind velocity direction. In such region, dominated by the formation and shedding of large vortices, the pressure is always below ambient value. The first results of an experimental research are presented in this paper. They were conducted in a small wind tunnel and the model was made of plastic water tubes and curves joined to aluminum flat plates with different diameters, in order to verify the variations of the flow rate sucked due to changes in the bluff body characteristic dimension (external plate diameter). Square plates with and without end plates are also analyzed. Non dimensional and dimensional parameters are used to present the results. Finally, the present natural ventilation device is compared to a chimney, through a non-dimensional flow rate ratio.*

Key-words: *Natural ventilation, Bluff body, Experimental technique*

1. INTRODUCTION

In the figure 1, the device proposed in this work for promoting natural ventilation, is sketched at the roof of a building and is basically constituted of: (i) a well designed air entrance, designated by number (1), located inside the building, (ii) a straight tube (2), which is fixed at the building roof , (iii) a smooth bend, which can rotate relative to the straight tube axis, in order to keep a flat plate (4), located at the exit section, always normal to the wind velocity direction. Such device uses the well-known fact (see Roshko, 1953 and Fage & Johansen, 1927) that in the near wake region of a bluff body (in the present case, the flat plate), the static pressure is always below the ambient pressure of the wind flow. Therefore a flow is established inside the device, due to the pressure difference between the building interior and the device exit section, where the flow is discharged into the flat plate wake.

The main objective of the present work is to obtain quantitative results of the air flow rate sucked by the above described device. The experimental approach is used to accomplish the objective, because in the present case, it is faster and cheaper than the computational one.

Further more, the flow established at the near wake region is three dimensional, unsteady and the flow coming from the building (internal flow) interacts strongly with the vortices in the wake. The use of numerical methods for this kind of flow is still a challenge, in the sense that solutions should be validated before someone could have confidence in the results, therefore, such validations would be necessarily made with experimental results, like the ones shown in this paper.

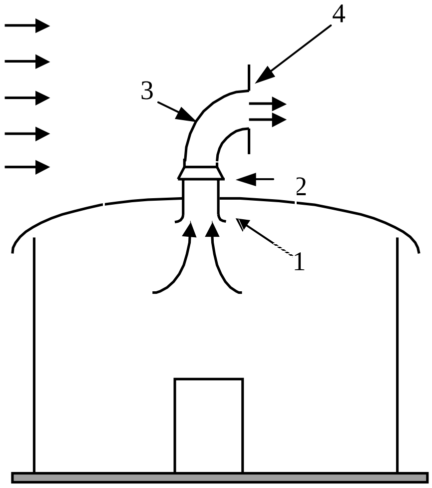

Figure 1 - Natural ventilation device at a building roof

Considering the present configuration, it is reasonable to expect that the relation between the plate characteristic length (D) and the exit section diameter (d) of the curved tube can have some influence on the flow rate sucked. This affirmative can be justified by the following reasoning: The flow rate sucked from the building must be a function of the base pressure coefficient and of the pressure losses occurring in the flow inside the tube. On the other hand, the base pressure is a function of the interaction between the external flow, caused by the passage of wind over the plate, and the internal one, which comes from the building interior. Such interaction occurs at the formation region (near wake) and, the base pressure coefficient increases when a flow rate is introduced into the near wake of a bluff body, as shown by the results obtained by Bearman (1967). Therefore, a base pressure decrement and, consequently, a flow rate sucked increment is expected, when the relation D/d is increased, because the flow rate introduced in the near wake certainly will have a lesser relative value for greater values of D/d.

Other possibility, that is worth to be investigated, is the implementation of a configuration constituted by a square plate and two end plates, located at opposite edges. Such configuration would approximate a two dimensional flat plate (see Bearman, 1965), which is characterized by a lower base pressure coefficient than the one obtained with a three-dimensional bluff body, like circular or square plates.

2. EXPERIMENTAL APPARATUS

The measurements were performed in a blower wind tunnel with 460x460 mm test section. The flow velocity ranges from 4 to 30 m/s and the turbulence intensity is 0.5% at the maximum velocity. The model was fixed at the exit section of the test chamber, as shown in the figure 2

The circular flat plate, shown in the figure 2, was made of aluminum and is characterized by a fixed internal diameter, d=0.0441 m, and an external one (D), which can be varied in order to change the diameter ratio (DR) from 1.0 to 4.0. The blockage ratio is equal to 11.5% for the greater value of the external diameter.

As explained above, this circular plate is fixed to a 90 degrees tube bend, with internal diameter equal to 0.0441 m. The bend is made with plastic material, with low internal roughness, and its radius is equal to 0.1 m.

The straight tube connected to the bend is 0.132 m long and has the same internal diameter. It is made with the same material as the bend and, in fact, they are commercial hydraulic elements applied to residential cold water installations.

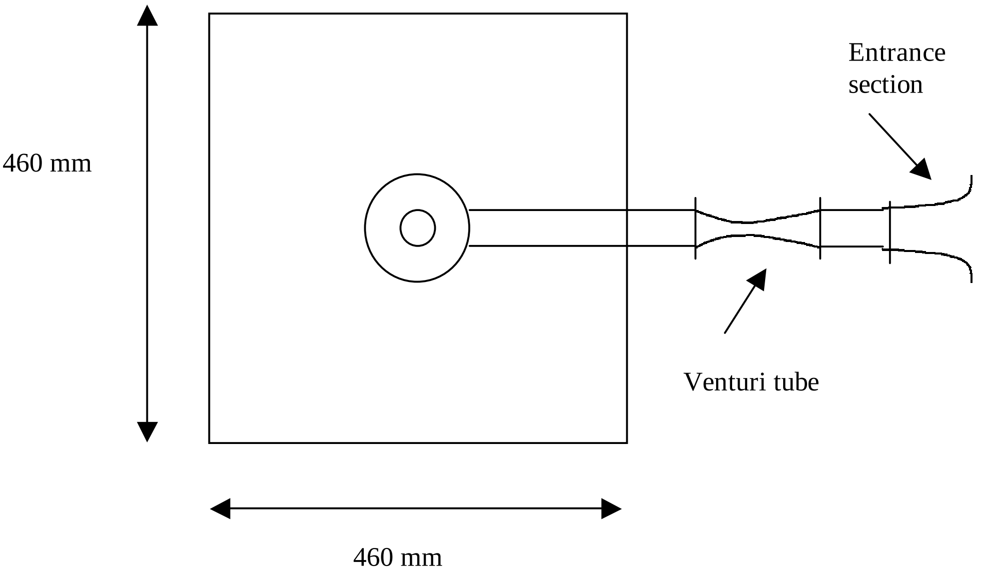

Figure 2- Frontal view of the wind tunnel exit section with the natural ventilation model installed

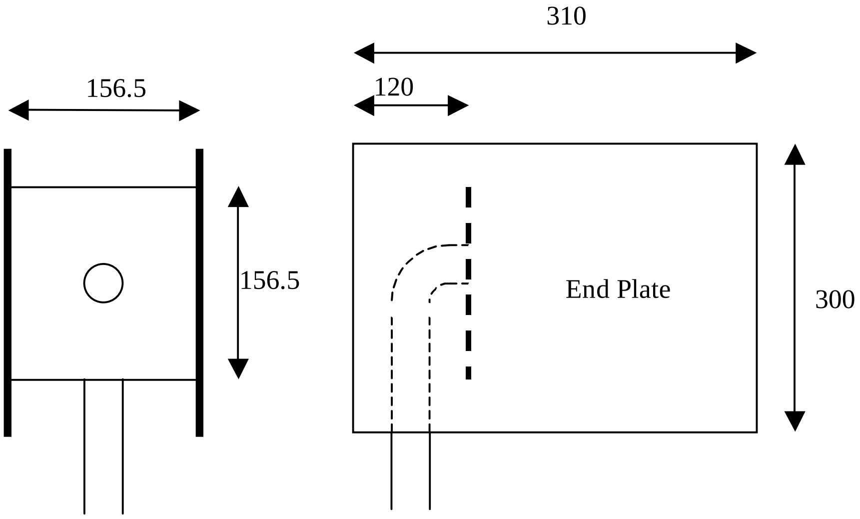

Figure 3: Frontal and side views of the square plate with end plates

A fiberglass made Venturi tube is attached at the end of the straight tube and it was specially designed for this experiment, because of the low values of the flow rate sucked by the reduced model tested in the wind tunnel. The Venturi tube is characterized by the diameter ratio $\beta = 0.522$ and its discharge coefficient was obtained, through a calibration, as a function of Reynolds number.

Other straight tube (0.345 m long) is used to join the Venturi tube to a bell mouth shaped entrance section, made with fiberglass and designed to minimize the pressure losses.

An aluminum square plate with side length equal to 0.1565 m and with a central hole with a 0.0441 m diameter was prepared to be tested in the place of the circular plates. This square plate has the same area than the circular one with diameter ratio DR=4,0. Two aluminum end plates can be fixed at opposite sides of the square plate and aligned to the wind velocity direction, as shown in the figure 3.

The information required for this research can be obtained by measuring a pressure difference at the Venturi tube (for obtaining the flow rate sucked by the device proposed) and a second pressure difference at a Pitot tube, placed at the test section entrance, for determining the dynamic pressure and the wind velocity. These parameters are measured with two pressure transducers, connected to two channels of a signal conditioning equipment. The amplified voltages are sent to an acquisition system based on a microcomputer (Pentium 100 Mhz) with a National Instruments board, capable to acquire 64 channels with a maximum sample rate of 500 Khz. The LabView software is used to control acquisition process and to analyze data obtained during the tests. Some codes were developed and used during the several phases of the present research program.

3. EXPERIMENTAL PROCEDURE

The initial phase of this work was dedicated to perform the Venturi tube calibration, which was a difficult task due to the very low values of the flow rate sucked (from 0.4 to 4.0 l/s) by the model tested in the wind tunnel. In fact, the Venturi tube, the entrance section and the straight tube joining these elements were calibrated together in order to avoid problems associated to the small distance separating the Venturi tube and the entrance section. A special apparatus was used to conduct the calibration and the discharge coefficient of the configuration was obtained as a function of the Reynolds number.

The Pitot tube, used to obtain the dynamic pressure, was calibrated with a standard Pitot tube located at the test section exit, where the model is installed during the experiments. A small difference was detected and this can be explained by a flow distortion observed at the end of the wind tunnel contraction and at the test section entrance, where the Pitot tube is installed. The calibration curve is used to correct the measured dynamic pressure.

For each test, the model was carefully located at the test section center and the circular (or square) plate was placed parallel to the tunnel exit section, in order to guarantee that this plate is perpendicular to the wind velocity direction.

The two pressure transducers, used in this experiment, were calibrated simultaneously before each test and a Betz manometer was used as a secondary standard. This kind of calibration procedure was possible due to the acquisition system described in the preceding section and avoid time and effort waste.

The dynamic pressure was incremented from 0.5 to 40 mm of water during each experiment. For lower values, steps less than 1 mm were used and for the larger ones, the maximum step used was about 3 mm of water.

For each value of the dynamic pressure the acquisition program takes 1000 samples during a time interval of 5 seconds. Average values for the dynamic pressure and for the Venturi tube pressure difference are stored in the computer.

At the end of a specific test, ambient pressure and temperature are measured in order to determine air density and dynamic viscosity.

The procedure above was used for each test conducted in this experimental program.

In the first phase, circular plate was used and the diameter ratio (DR) was varied, assuming values equal to 1.0, 2.0, 2.5, 3.0, 3.5 and 4.0. The configuration with DR = 4.0 was tested in three different opportunities in order to verify the repeatability of the experimental procedure.

In the second phase three experiments were conducted with: (i) the square plate, (ii) the square plate fitted with end plates, placed horizontally and (iii) the square plate fitted with end plates, placed vertically.

In the last phase, the natural ventilation device was replaced by a straight tube with internal diameter equal to 0.0441 m and length equal to 230 mm. One end of this straight tube was connected to the Venturi tube and the other was placed at the test section center. Such experiment was performed to obtain data for a chimney model, which can be used to compare the device proposed in this work to other natural ventilation devices.

The experimental data reduction was performed with the tools available in the Labview software and the uncertainty analysis was made using the procedure described in Kline & Mcintoch (1953).

4. ANALYSIS OF RESULTS

The wind velocity (V) and the internal tube diameter (d) were used to define the non-dimensional flow rate ($Q/V.d^2$). This parameter is a function of the Reynolds number (Re), which uses d and V as the characteristic dimension and velocity, respectively.

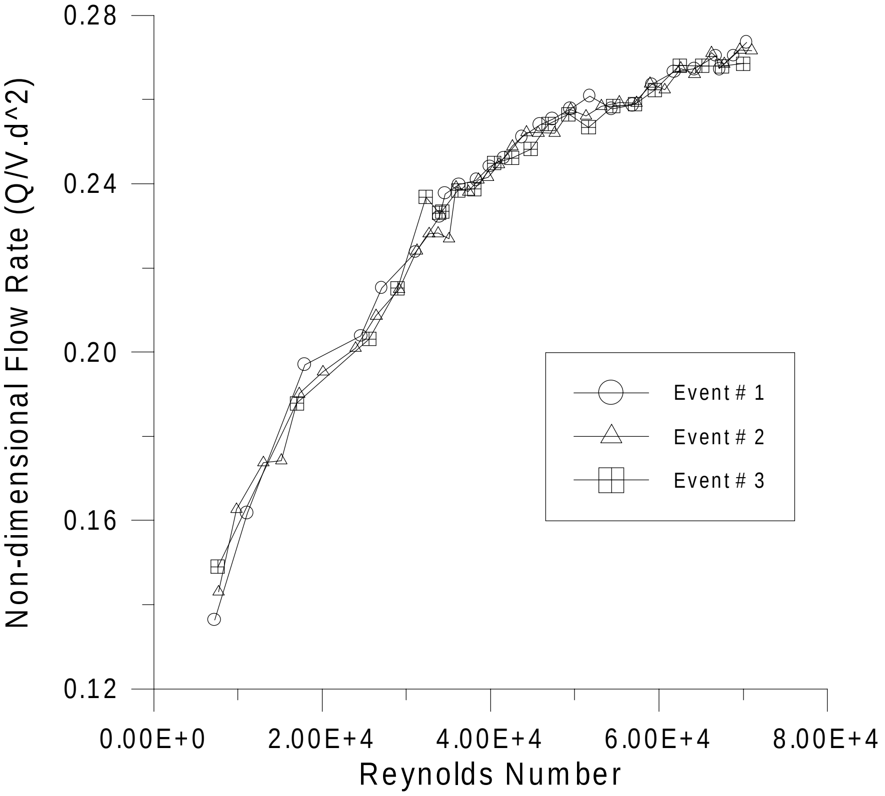

Figure 4- Results obtained in three different events, for the circular plate with diameter ratio 4.0

The experimental results for the circular plate with diameter ratio, DR = 4.0 are presented in the figure 4. These data were obtained in three events, conducted in different days, with different calibration curves for the pressure transducers. Good agreement among the three data sets can be observed, mainly for the larger values of the Reynolds number, showing that the experimental procedure adopted in this work produces results with good repeatability. It must be remembered that the lower Re values were obtained with dynamic pressures near 1 mm of water and, therefore, greater uncertainty was already expected for that.

The flow rate (Q) sucked by the natural ventilation device proposed in the present work, for different diameter ratios of the circular plate, is shown in the figure 5, as a function of the wind velocity. In the same figure, the results obtained for the chimney model are plotted. For lower values of wind velocity, the flow rate increment is smaller than for the larger ones. Such behavior also occurs for the chimney but is less pronounced. The same observations can be verified in the figure 6, where the non-dimensional flow rate is plotted as a function of the Reynolds number. This behaviour for the flow rate may be explained by changes of the pressure loss of the tube internal flow or by changes in the base pressure coefficient, due to the influence of the flow leaving the tube inside the wake formation region. The lower variations of the flow rate increment for the chimney indicates that the pressure losses of the flow inside the tube and, in particular, the pressure loss in the curve can be the responsible for the behavior mentioned above. The results for DR=1.0, that is, for the case where no plate is used in the device, is another indicative that the base pressure coefficient must have less importance in the variation detected for the flow rate increment.

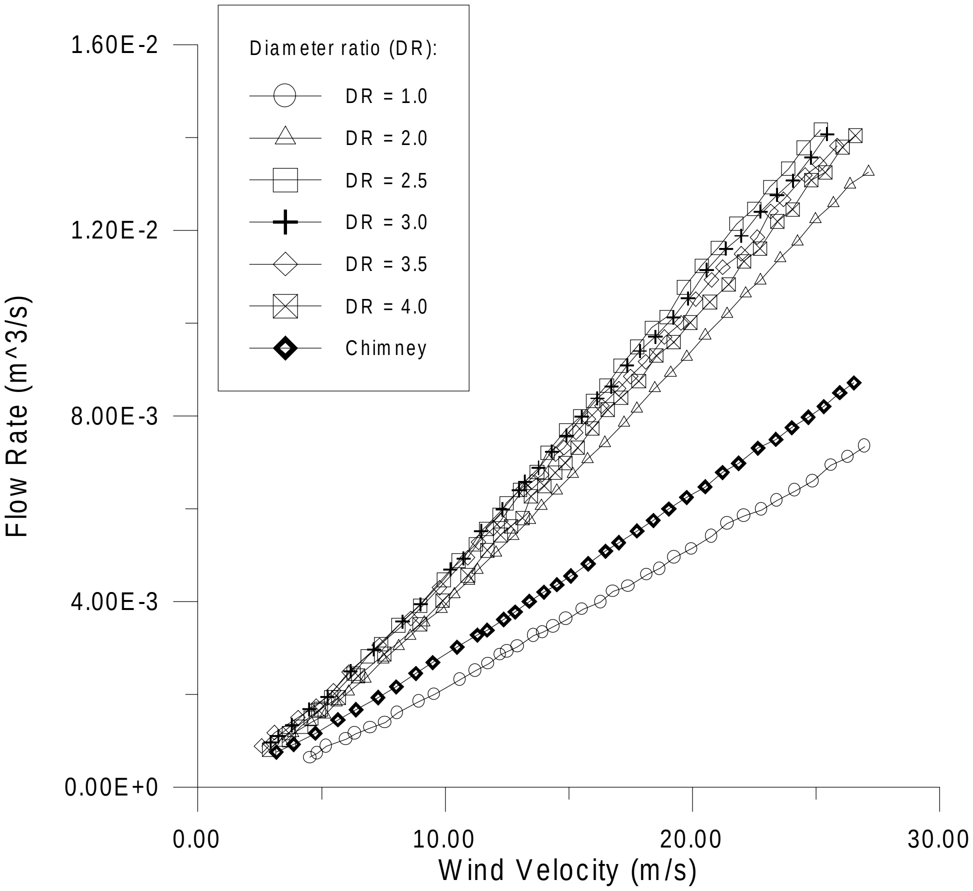

Figure 5- Flow rate sucked as a function of the wind velocity, for circular plate with several diameter ratios.

As can be seen in the figures 5 and 6, the flow rate sucked by the studied device with DR=1.0 is smaller than the value obtained by the chimney. This result can be explained remembering that the above configuration has only one curve more than the chimney model and, therefore, the pressure loss in this curve can be the cause for the smaller flow rate sucked. Moreover, the flow patterns of both configurations at the exit section are different and the pressure coefficient at these exit sections can have different values.

In figure 5 and, mainly, in figure 6 it is possible to observe that the curves for each diameter ratio are approximately parallel, except for the configuration with DR=2.5, for the lower values of the Reynolds number range. This exception has to be

confirmed with additional experiments before any explanation tentative, because, as mentioned before, the uncertainty values are greater for the lower range of Reynolds number. A very interesting observation can still be verified from the above two figures: for the same value of the Reynolds number (in the upper part of its range), the flow rate has an increment while the diameter ratio is varied from 1.0 to 2.5, where a maximum occurs. A slow decrease of the flow rate is verified when the diameter ratio is increased from 2.5 to 4.0. The expected result, at the beginning of this work, was a continuous increment of the flow rate, with a tendency to a superior limit value, while the diameter ratio was increased. This expectation is justified by the following reasoning: the flow rate proceeding from the tube would become small in comparison to the formation region dimension and, therefore, would have a smaller influence to this flow as the diameter ratio was increased. The experimental result reported above cannot be explained with the information available up to now but the blockage ratio effect is one the possible reasons (see Glauert, 1933), because for the model with diameter ratio 2.5, the blockage ratio is 4.5% and for the greater models, the blockage ratio is in the range between 6.5% 11.5%.

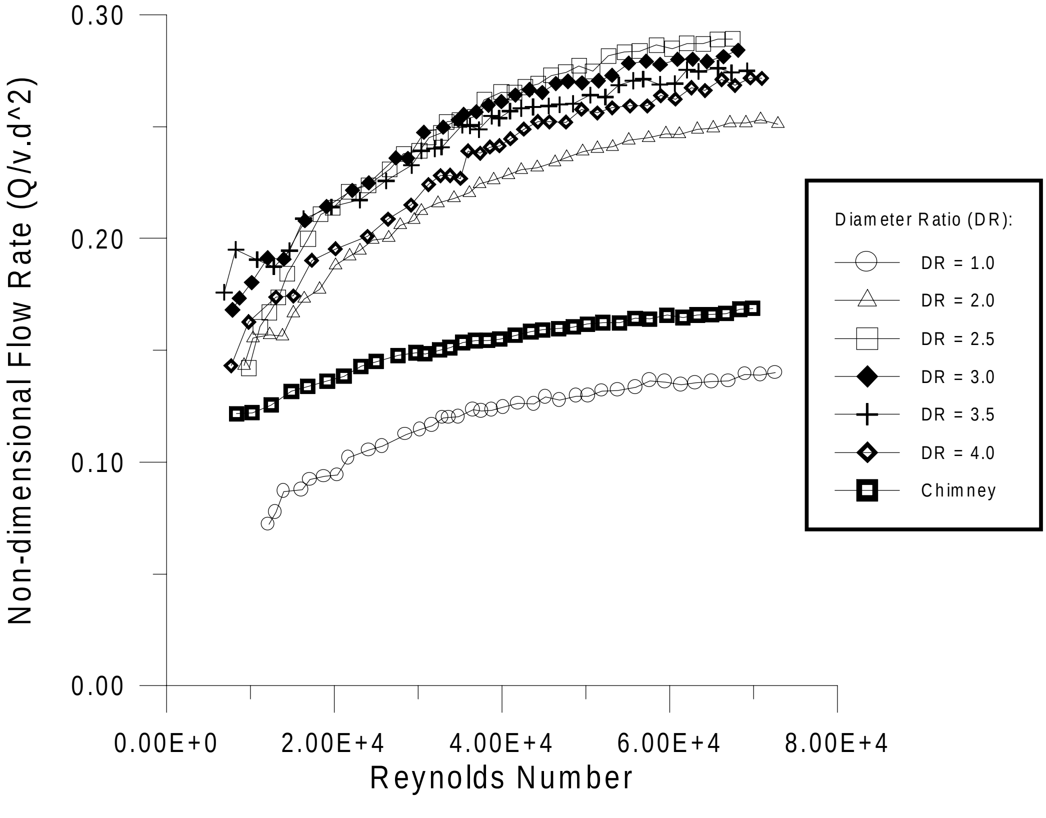

Figure 6- Non-dimensional flow rate sucked as a function of the Reynolds number, for circular plate with several diameter ratios

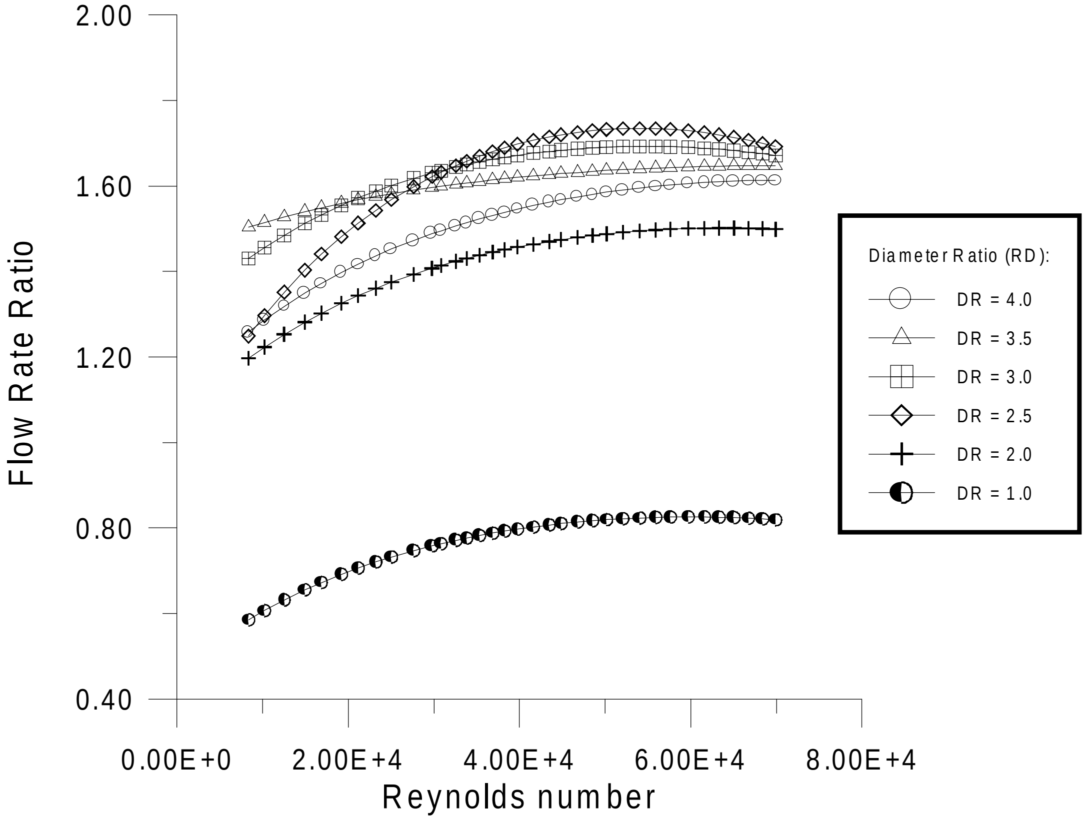

Figure 7- Non-dimensional flow rate ratio between present device and chimney, for circular plate with several diameter ratios

The flow rate ratios between the natural ventilation device proposed in this work and the chimney are shown in the figure 7, for the considered diameter ratios. These results were obtained after a curve fitting of the experiments presented in the figures 5 and 6, because the Reynolds number obtained during the tests were not exactly coincident to the values measured for the chimney. The maximum value of this parameter is 1.73 for a Reynolds number equal to 5.40×10^4 for the configuration with diameter ratio 2.5. At this moment, it is adequate to point out that the values presented for the flow rate can not be used without correction, because the experimental results are influenced by the Venturi tube pressure loss. The absolute values for the flow rate are greater than the values reported in this paper. Meanwhile the flow rate ratios, shown in the figure 7, are correct values because the Venturi tube pressure loss has approximately the same effect in the chimney results.

As can be seen in the figure 8, the installation of the end plates used in this work has a negative effect in the flow rate sucked by the proposed device. Again, this is an unexpected result because two-dimensional bluff bodies have lower values of the base pressure and, then, in principle, they would have more potential for promoting suction. A possible cause for the above result is the end plate effectiveness, in the sense that the flow over the square plate is not two-dimensional. Other possibility is an increment of the blockage ratio effect, due to the fact that the flow over the square plate was, at least, partially influenced by the end plates. Here, it is interesting to remember that, for the same model dimension, the two dimensional blockage ratio effect is stronger than the three dimensional one. As can be seen in the figure 8, the flow sucked is almost the same for the configurations with horizontal and vertical end plates. This result shows that the flow over the square plate is not significantly disturbed by the tube straight part. It must be emphasized that the straight tube is placed in the horizontal position during the tests, as can be seen in the figure 2 and, therefore, smaller influence was expected for the configuration with vertical end plates, because the square plate horizontal edges are less perturbed by the straight tube wake. The results for the circular plate, with diameter ratio 4.0, are also presented in the figure 8, and they are almost coincident with the ones obtained for the square plate without end plates.

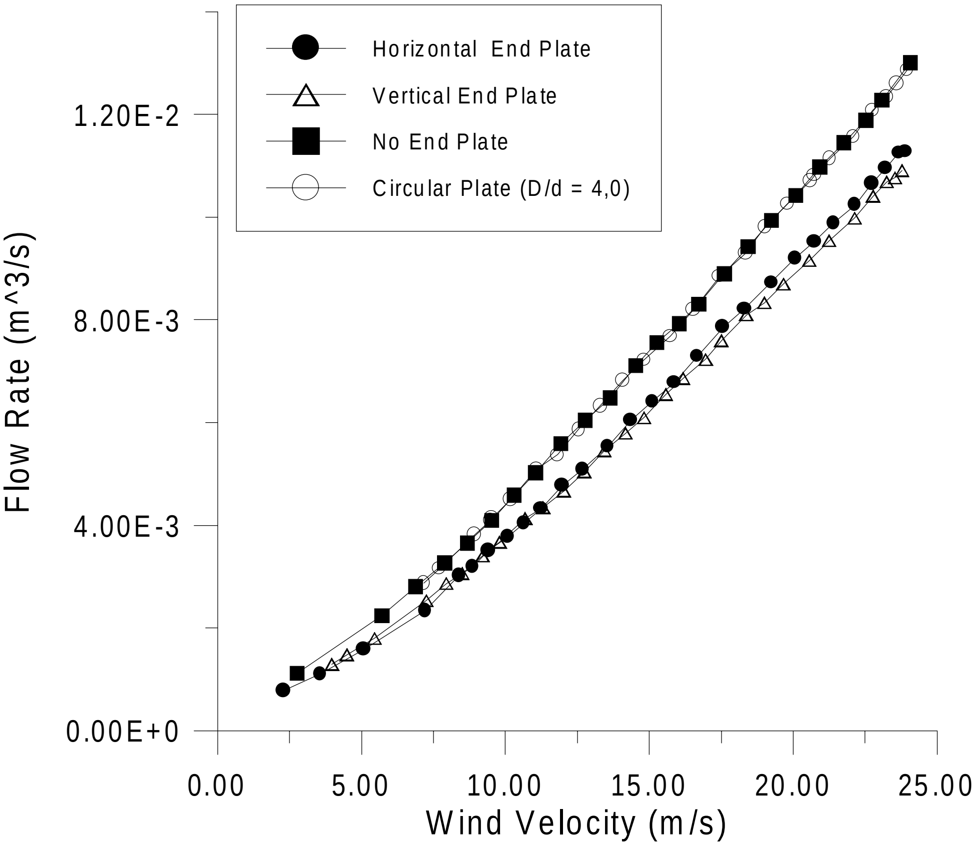

Figure 8- Effect of end plates on the flow over the natural ventilation device with a square plate

5. FINAL REMMARKS

The results reported in this paper are the beginning of an extensive research program, whose final objective is to understand as much as possible the flow pattern over the natural ventilation device proposed in this work. As mentioned before, the base pressure coefficient is one of the most important parameters for the sucked flow rate establishment. Such parameter is greatly influenced by the interaction occurring in the base region, between the flow proceeding from the tube and the wake flow, dominated by the vortex interaction in the formation region. This kind of flow is not simple to be studied and much more information must be obtained before the above objective be reached.

For the case where a circular plate is used, a maximum for the flow rate sucked was found for the diameter ratio 2.5, for which the flow rate value is approximately 70% greater than the one sucked by a chimney. Considering the author’s knowledge, this value is greater than any other device in use now days. The initial analysis of the experiments indicates that the pressure loss at the device curve is an important parameter and, thus, additional improvements can be obtained by introducing guiding vanes at such curve to diminish the pressure loss.

The use of a square plate in place of a circular one (both with the same area) do not cause any influence in the flow rate sucked. This information can be useful to make easy the device manufacturing. On the other hand, the use of end plates installed at the square plate edges cause a decrease in the flow rate sucked. This result can not be considered as definitive, because other end plates configurations can give better results.

There are many activities to be done in future work but, the experimental data for the flow rate must be corrected and this task can be accomplished by measuring the pressure loss associated to the Venturi tube. This correction will be useful to specify the dimension and the number of the devices that have to be installed at a building, in order to promote the natural ventilation.

Acknowledgements

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