Analogical Visualization of Natural Ventilation in Buildings due to Wind Action

Fernando O.R. Pereira¹ and Alexandre M. Toledo²

¹ Federal University of Santa Catarina, Civil Eng. Postgraduation Course, Florianópolis, Brazil
² Federal University of Alagoas, Maceió, Brazil

ABSTRACT: The aim of the present paper is to show the first evaluations of several airflow simulations performed with physical scale models, using the tracer method with a technique of direct injection of detergent in the water, with a water table apparatus, developed in the LabCon/UFSC/BR. The studies have clearly shown that the equipment has several advantages: it allows for an instantaneous and dynamic visualization of the airflow outside and inside the building models, as well as a direct definition of the inlet and outlet openings. The photographic record of the experiments, made with a digital camera, makes the airflow analyses a very intuitive, effective and amusing task. One can conclude that, although the proposed technique is an analogical model and allows only for bi-dimensional airflow visualization, the water table appears to be a very effective didactic tool for supporting the teaching of natural ventilation of buildings.

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1. INTRODUCTION

Natural ventilation of buildings due to wind action is significantly relevant in order to provide users thermal comfort in warm and humid conditions, usual conditions in most of Brazilian territory.

The behaviour of airflow outside and inside the buildings can be calculated by CFD (Computer Fluid Dynamic) codes, which results allow for quantitative and qualitative evaluation of the phenomena. As a main drawback, CDF’s are still difficult and cumbersome to be used by designers and architects [1], because of the high initial cost and the need of deep knowledge on computer and numerical modeling, besides showing a long processing time.

The visualization techniques of airflow using physical scale models, although partially surpassed by the fast development of CFD’s, are a very feasible alternative, especially due to its low cost [2].

The indicators that can be used in a liquid medium, for the visualization of extended lines or large continuum areas are dyes, pigments, oil, milk, soap bubbles and luminous particles; and for separated particles one can use sawdust, aluminum powder and bakelite [5].

3. METHODS AND TECHNIQUES

The main methods and techniques for flow visualization are: tracing method, by direct injection, chemical reaction and electric control techniques; the tuff method, by surface, depth and mesh techniques; and the optical method, by the use of shading, Schlieren, interferometry and holografy techniques.

The tracing method and direct injection technique are the most preferred for analogical experiments of natural ventilation in buildings, because they use low velocity (up to 2 m/s), which are adequate for uncompressible outflows.

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4. METHODOLOGY APPROACH

The methodological approach for the present study was based on a series of the didactic exercises
(PANCA 5), developed during the undergraduate course of Architecture and Urbanism from UFSC, which consists of four stages:

1) buildings selection – was given preference to residential buildings of different typologies and requirements program.

2) scale models making – the models were made of different materials (plywood, pasteboard and Styrofoam) and scales (1:100 and 1:50).

3) experiments development – the studies were developed in a water table, with the tracing method using the direct injection technique (detergent in the water); visual observation of the qualitative water flow for the main wind directions and different window configuration were made, and registered by digital photography.

4) results analysis – it was developed with the photographic images, drawings and textual description of the flowing off behavior, through the identification of windward and leeward surfaces, inlet and outlet apertures, besides the trajectories and the flowing off influence zones for inner and outer spaces.

4.1 Water Table Apparatus of LabCon/UFSC

The Water Table (developed by LabCon/UFSC) consists of a horizontal glazing tray over which the water flows in a certain direction with an uniform speed, creating the field of the experiments and observations. This tray is supported by a metal structure with levellers and wheels, that allow for its correct displacement (figure 1).

![Figure 1: Water Table Apparatus of LabCon/UFSC](image)

Two tanks (stoss and lee side) with 90 litres each are situated at the two opposite ends of the tray.

A hydraulic and an electric system complete the apparatus. The first one is made of 1" pipes, which starts at the bottom of the lee tank, goes to the electric pump and ends at the bottom of the stoss tank. The electric system consists of a 0.75 HP pump, 60 Hz and an electric inverter, 200-240 VA, 60 Hz of maximum frequency. This system allows for pumping the water from a very low outflow up to the a maximum of 9.6 m³/h.

4.2 Wind profile in Florianópolis

The city of Florianópolis (27°40’ of South latitude and 48°33’ of West longitude) is the capital of Santa Catarina State, in southern Brazil.

An interesting particularity of the wind profile in Florianópolis is the opposite direction of the prevailing occurrences (North and South) along the whole year.

The most frequent wind directions are North and South, followed by NE and SW. Winds from East and West are the least frequent.

The annual wind occurrence frequencies for the Northern quadrant (NW, N and NE) sum up to a total of 49.58 %, whereas for the Southern quadrant the total sums 37.54 %. The prevailing direction of North and South are maintained along the seasons.

5. EXPERIMENTAL STUDIES

In order to show the methodology potential, two experiments, developed by undergraduate architecture students during 2003, were selected.

5.1 Multi-family housing with complex geometry

The first study analysed a housing building with six units per pavement. The peculiar and complex geometry of this building presents windows in all possible eight directions, a situation that consists of a paradox for the definition of the preferable orientations for window location.

Several trials were performed for four wind directions, and for three different situations: (i) all external windows closed; (ii) all external windows open and the bathroom door closed; (iii) windows and bathroom door open. The experiment observations are presented as follows:

**Outflow from North direction (North wind)**

(i) zones of low pressure, similar to lateral zones, are formed, on the recessed planes of windward units number 4, 5, 6 and 1. The wake appears at the South planes and at the planes of units 1 and 2 (SW) and 3 and 4 (SE) (figure 2).

![Figure 2(a,b): Outflow from North – situation (i)](image)
(ii) one can note a little airflow in the units (5, 6, 4 and 1) with windward windows, due to the uni-laterality of the window system. There is a wake formed at leeward planes and at the side planes of units 1 and 4; the leeward units 2 and 3 do not present any airflow (figure 3).

![Figure 3(a,b): Outflow from North – situation (ii)](image)

(iii) it is perceived a larger airflow in the units with windward windows (5, 6, 4 and 1), due to the windows location, providing cross-ventilation. The wake which appear at leeward and lateral planes in the units 1, 2, 3 and 4 are also clearly noticed; and the units 2 and 3, in a leeward position, does not present any airflow (figure 4).

![Figure 4(a,b): Outflow from North – situation (iii)](image)

**Outflow from South direction (South wind)**

(i) there are two zones of re-circulating at the windward recessed planes of units 2 and 3. The wake appear on leeward side (North) and on the lateral planes from units 1 and 6 (NW and W), and units 4 and 5 (NE and E) (figure 5).

![Figure 5(a,b): Outflow from South - situation (i)](image)

(ii) it is perceived a discreet air circulation in the units (2 and 3) with windward windows due to the uni-laterality of the windows system. There is a wake formed at North planes and at the side planes of units 1, 4, 5 and 6; at the leeward units 1, 2, 6 and 5 there is no any airflow (figure 6).

![Figure 6(a,b): Outflow from South - situation (ii)](image)
Figure 6(a,b): Outflow from South - situation (ii)

(iii) it is perceived a larger airflow in the units with windward windows (2 and 3), and units 1 and 4 (bathroom windows situated at windward), due to the differentiated windows location related to each housing unit, providing cross-ventilation. A wake appears at North side, but it is visibly reduced at the lateral planes of units 5 and 6, with no air circulation in those units (figure 7).

Figure 7(a,b): Outflow from South - situation (iii)

The main conclusions of this first study are that the complex and peculiar geometry of the building plant creates different conditions for the realization of natural ventilation due to wind action in the six housing units. The units 2 and 3, facing South, do not get very much from the winds from Northern quadrant (NW/N/NE); while the units 6 and 5, facing North, followed by units 1 and 4, facing West and East, respectively, show a very low performance regarding natural ventilation due to southern winds (SE/S/SW).

5.2 Single family with simple geometry

The second study used a single-family housing, located in a lot of 12x30m, organized in two rectangular parts: the first one accommodating the social area and the second one, the private spaces.

The single form of this building corresponds to a representative housing typology very much in use with typical urban lots, presenting a particularity of locating windows in all four planes: to the front yard (South), to the back (North) and for the both sides of the lot (East and West).

There were developed several experiments for the eight main wind directions and for five different situations: (i) all external windows closed, (ii) all external windows open, (iii) bathroom and service sector doors closed, (iv) bathroom windows open and windows from the service area closed. The experiment observations are presented as follows:

Outflow from North direction (North wind)

(i) lateral low pressure zones are formed, enlarging the final zone at the recessed plane, which corresponds do the veranda area, apparently situated at windward. A wake appears at the South side (figure 8).
(ii) the outflow wakes, through the residence, occurred as follows: the North windows, master room, room 2 and living/dining room work as an air inlet zones, while the bathrooms, room 1, corridors, kitchen and South windows work as air outlet zones. The airflow from the master room merges with the airflow from the room 2, room 1 and living room ones. The wake at the South side is dissipated (figure 9).

(iii) there are changes in the outflow path throughout the spaces: the North windows, master room and living/dining room work as air inlet zones, and the room 1, corridor and the South windows work as air outlet zones; The room 2 does not show any airflow. The airflow from the master room is divided between the room 1 and the corridor, with part going out and part follows towards the living room. The wake at the South side is dissipated (figure 10).

(iv) this situation does not show any significant change in the outflow trajectory inside the residence, and the situation.

Outflow from South direction (South wind)
(i) lateral low pressure zones are formed, enlarging the final zone at the recessed plane, which corresponds do the veranda area. A dragnet or wake appears at the leeward side (North) (figure 11).

Figure 8(a,b): Outflow from North – situation (i)

Figure 9(a,b): Outflow from North – situation (ii)

Figure 10(a,b): Outflow from North – situation (iii)

Figure 11(a,b): Outflow from South - situation (i)
(ii) the outflow wakes, through the residence, occurred as follows: the South windows from the living room work as the only inlet openings, and all the other spaces work as air outlet zones. The airflow from the living room is divided between the kitchen and the corridor, and from the corridor goes towards the room 1 and 2, the bathroom and the master room. The wake at the North side is dissipated (figure 12).

(iii) several changes in the trajectories are perceived: the South windows from the living/dinning room are still the only air entrance, and the room 2, corridor, master room and the North windows from the living room work as air outlet; the room 1 does show any airflow. The airflow in the living room divides towards the exterior and the corridor, which by its turn leads the airflow to the outside and to the room 2 and master room. The wake at the North side is partially dissipated (figure 13).

(iv) there is no significant change in the outflow trajectory inside the residence.

It is worth mentioning from the observations done in the second study that despite of the simple dwelling geometry, different situations for natural ventilation due to wind action are generated because of opposite direction (North and South) for the predominant winds in Florianópolis.

6. CONCLUSIONS

This paper has shown the first evaluations of several analogical airflow simulations performed with physical scale models, using the technique of direct injection of detergent into the water, with an apparatus called Water Table, developed in the LabCon/UFSC, Brazil.

The studies have clearly shown that the equipment has several advantages: it allows for an instantaneous and dynamic visualization of the airflow outside and inside the building models, as well as a direct definition of the inlet and outlet openings. The photographic record of the experiments, made with a digital camera, makes the airflow analyses a very intuitive, effective and amusing task.

One can conclude that, although the proposed technique is an analogical model and allows only for bi-dimensional airflow visualization, the Water Table appears to be a very effective didactic tool for supporting the teaching of natural ventilation of buildings.

REFERENCES


