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Understanding Ventilation in Graduation School: Wind Tunnel a Projectual Aid Tool

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Abstract: *The studies developed at the School of Architecture and Urbanism at Federal University of Rio de Janeiro - FAU/UFRJ, using the project aid tool, wind tunnel (WT), deal with simulation of scenarios, real or hypothetical, to produce comparative diagnosis and analysis of the effects of the wind relative to the built volumes and empty spaces. From the diagnostics, wind effects can be positive or negative in relation to the tropical climate, for the various proposals and existing urban provisions. This research is directly related to the visualization of experiments. The aim is to develop didactic materials and experiments to facilitate the visualization of the wind trajectories in urban and architectural models. The tests allow designers to recognize their ability to interfere with the dynamics of wind, often through simple changes, which may result in substantial gains in environmental comfort. Architectural and urban have been developed for use in the experiments.*

Keywords: *experimental simulation, habitation module, urban module, ventilation, wind tunnel*

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I. Introduction

Understanding the importance and the possibility of interfering with the ventilation of environments through certain projects in architectural and urban morphology can contribute to the planning of architectural and urban spaces with a higher quality of comfort for users.

Among other objectives, the studies developed with wind tunnel deal with simulation of scenarios, real or hypothetical, to produce comparative diagnosis and analysis of the effects of the wind relative to the built volumes and empty spaces. From the diagnostics, wind effects can be positive or negative in relation to the tropical climate, for the various proposals and existing urban provisions.

The adequacy of an architectural or urban project depends on site characteristics. These characteristics need to be understood in both physical and cultural aspects, to be able to promote favorable conditions for health, comfort, and enjoyment of environmentally conscious users and to optimize the use of energy resources in architecture [1]. The bioclimatic conception of public space aim by acting in urban scale the same as bioclimatic architecture reaches the building itself, i.e., transform this into a mediator between the outside environment and the inside framed of public space [1]. Thus, conceived public space is treated as a unit, where the elements (environmental, climatic, historical, cultural, and technological) interact and act as stimuli to the dimensional order of the space.

Therefore, it is essential for the adequacy of the project to develop tools that enable support for design decisions. For ventilation, it is important to implement measures to encourage the understanding of what happens in terms of ventilation in the architectural and urban spaces. Through the observation of the wind field, it is possible to identify the most ventilated areas, as well as those with poor ventilation.

The research at School of Architecture and Urbanism at Federal University of Rio de Janeiro - FAU/UFRJ, using the wind tunnel - WT, aims to develop experiments and didactic materials to facilitate the visualization of the wind trajectories in urban and architectural models [2]. The comprehension of the ventilation phenomenon, when shown visually, facilitates student learning. The activities related to WT/FAU also include the development of didactic materials conducive to immediate perception, through the display of the wind trajectories. Thus, this meets the needs of students and professionals whose areas of knowledge training are scheduled in the visual understanding of space. A "library of experiments" is also constructed to supplement the learning process, indicating the need for interventions in architectural and urban spaces. This practical learning process is connected with what was learned in class, highlighting to students that they are not just observers but also actors in the evaluation of the wind effects and in so doing, they can impose or suggest changes on the models, and consequently, changes in the wind paths. The students and observers inside the wind tunnel laboratory are encouraged to suggest alterations on the position of the model or its elements and then to observe the effects of their action. This fact distinguishes this type of active observation resulting from the presentation of a film or video.

It is possible to observe that often, simple interventions can result in significant performance improvements in the experience of environmental comfort. Concerns on the location of the openings in architectural projects allow the adequacy of the project site conditions, selecting arrangements that privilege the thermal comfort of users, minimizing energy costs for mechanical ventilation. The evaluation of different forms of occupation in the area and other elements of urban morphology reflects the care with urban employment and helps in identifying areas where there is little natural ventilation. This action can be followed by a study related to solar radiation, which allows evaluating the possibility of the formation of heat islands. Thus, the wind tunnel is a key design tool for smart use of wind on buildings and urban spaces, contributing to the training of students in front of the changes in how to build, inhabit, and live.

During complementation of the experiments, visitors are invited to fill out a questionnaire whose answers can improve the process of submission, review of the methodology, and development of new experiments. This work has impact in the short, medium, and long term, as the acquired knowledge can be put into practice in college and future careers.

II. The Wind Tunnel

The wind tunnel (WT) of the School of Architecture and Urbanism of the Federal University of Rio de Janeiro - FAU/UFRJ is an experimental tool that allows the understanding of the interaction of the wind flow with buildings and their surroundings by using visualization techniques. Fig. 1a and 1b, respectively, show a lower plan and a side view of the WT/FAU. We note the detail of the drawers sector seen without the access door (images adapted from the Wind Tunnel Project FAU/UFRJ, 2005) (Fig. 1b). Fig. 2, presents the side view of the wind tunnel (Fig. 2a) and the detail of the drawers sector seen without the access door (Fig. 2b).The tunnel was developed by the Building Aerodynamics Laboratory - LAC / DECIV / PPGEC - UFRGS in 2005 [3]. It was mounted on an 8.80 m × 7.60 m room on the ground floor of the FAU/UFRJ and works with velocities higher than 10 m/s, which is desirable for the testing of eolic erosion [4].

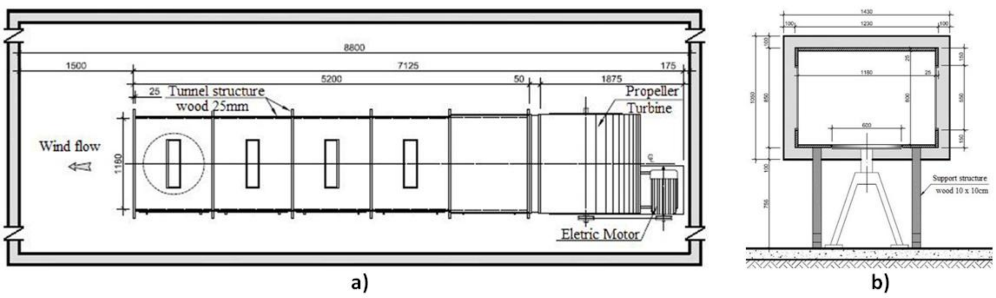


Figure1. Floor plan [a] and section [b] of the FAU / UFRJ (mm) wind tunnel - Image adapted from the Wind Tunnel Project - FAU / UFRJ, 2005.

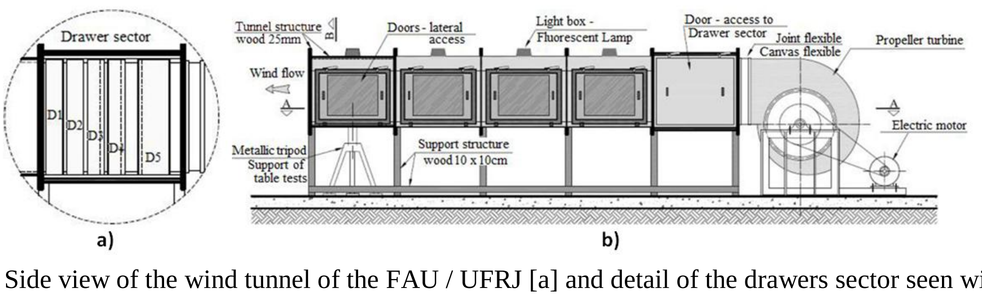


Figure 2. Side view of the wind tunnel of the FAU / UFRJ [a] and detail of the drawers sector seen without the access door [b]. Figure: Design of Wind Tunnel FAU / UFRJ, 2005 [3].

Figures 3a and 3b are photographic images of the side view and front view of the WT FAU/UFRJ; the test table can also be observed. This has a swivel mechanism, allowing the reduced models to be positioned appropriately for evaluation purposes, in relation to the wind direction. In the design of a wind tunnel, barrier layer is desirable that is at least a portion of the flow-over as it develops minimum amounts of different types of roughening.

a) **b)** **c)** **d)**

Figure 3. Side [a] and frontal [b] views of the wind tunnel. Obstacles acting as turbulence generators [c] and rough surface [d] of the FAU / UFRJ wind tunnel.

Thus, the development flow takes place through a long roughened surface representing the existence of a built environment. In the photographs of Figs. 3c and 3d are observed barriers called turbulence generators, with the shape of a shark's fin (Fig. 3c), and the roughened surface (Fig. 3d) over which the flow is developed before reaching the test table.

III. Reduced Models

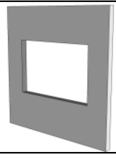
Reduced models were developed for testing in the WT. The models of architecture and urbanism areas were built by Scientific Initiation students from the research group Sustainable and Bioclimatic Urbanism – URBIS from FAU/UFRJ [5].

3.1. Residential Module Model

A reduced residential module was made with moving parts permitting a subdivision of the internal space and a relocation of the openings according to the interests of the observers. A modular housing model was constructed on special paper, to allow its opening position to be altered and its internal walls to be placed or not. The mobility of this model is essential for testing by enabling the suggested changes to be executed in sequence, that is, at the same moment that the idea arises, the test can be performed.

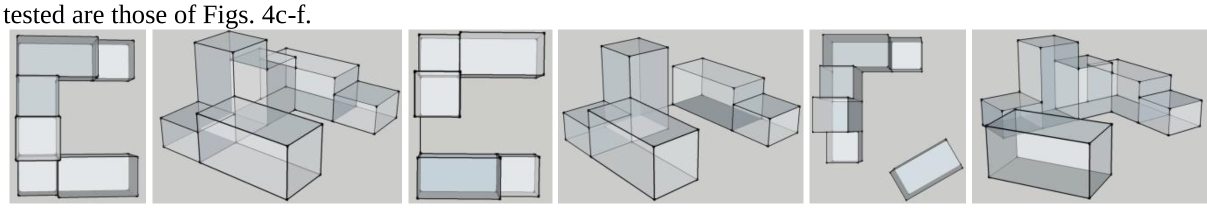
The various parts that make up the whole can be observed: the external module with walls positioned for docking (Table 1 – line 1 - a) and the assembled walls (line 1 - b), the internal module that allows the division of space into four parts (line 1 - c), and the complete module (line 1 - d). The four types of partitions are available both for internal and external walls in Table 1 – line 2; they are solid wall (a), side door (b), central door (c), and central window (d).

Table 1. Parts of the residential module model. Source: Drach and Corbella, 2010 [2].

a	b	c	d
			
			

3.2. Urban Models: Compact Blocks and Urban Area

Compact blocks of varying sizes were built, and they can be organized on the test table to make different arrangements representing urban areas. In a hypothetical situation, the blocks side by side without spacing are arranged forming a plan, a large "U", as can be seen in Figs. 4a and 4b. Among other arrangements tested are those of Figs. 4c-f.



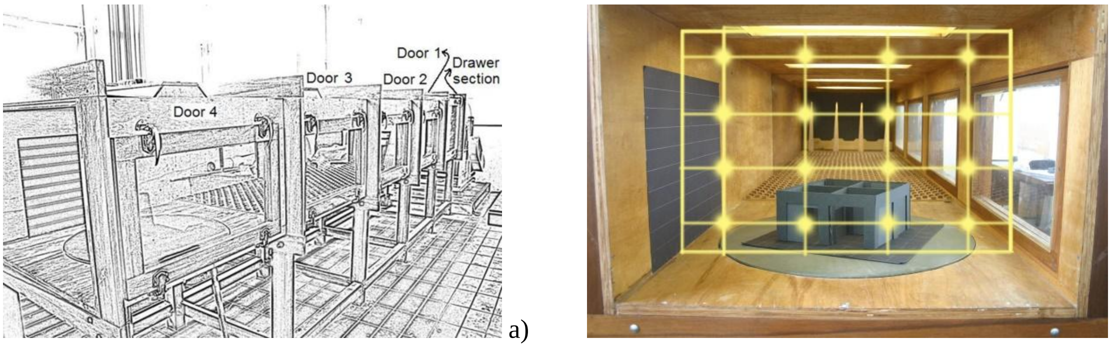
a) **b)** **c)** **d)** **e)** **f)**

Figure 4. Compact blocks: a "U" [a-b] "U" with opening [c-d] and with one of the blocks and angle [e-f]. Source: Drach and Corbella, 2010.

In assembling the urban model, care must be taken in relation to the materials because their repeated exposure during the experiment makes them very brittle, and they could end up falling off rapidly, damaging the model. The scale must be defined to meet some prerequisites; therefore, it is important to remember the adjustments between the dimensions of the model and the area of the test table. Another important setting is relative to the height of the buildings in relation to the dimension of WT from FAU/UFRJ, with higher than 15 cm or lower than 3 cm, considered not convenient.

IV. Methodological Procedures and Results

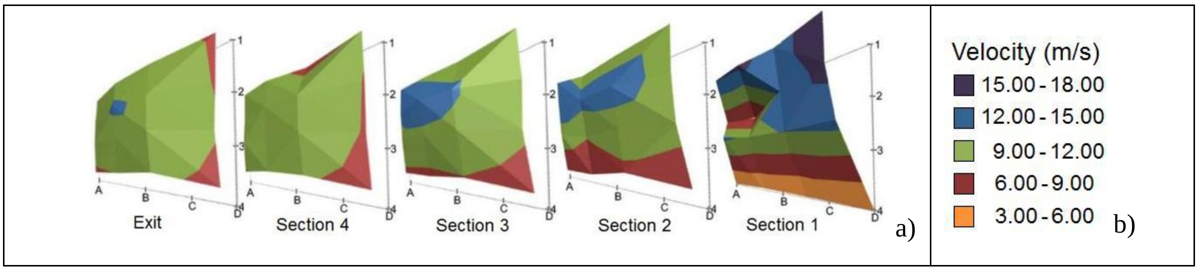
The airflow inside the wind tunnel was evaluated by measuring the variation of the air velocity along it using an anemometer (Testo 435 - temperature, humidity and air flow). The wind tunnel was mapped into 5 sections: drawer section, doors 1, 2, 3, and 4 (Fig. 5a), with 16 points in each section and arranged in a Cartesian grid with a total of 80 points (Fig. 5b).



a) b)

Figure 5. Wind tunnel mapped into 5 sections [a] and 16 points in each section [b]. Source: Henrique Drach images.

The values of wind velocity readings for each section were generated. As expected, for the closest regions to the wind turbine, airflow presents higher variation of velocities along the Cartesian plan. However, this airflow becomes uniform as it travels through the path inside the tunnel, and at the end, the flow stabilizes as can be observed from Fig. 6 (XXXVI Jornada Giulio Massarani de Iniciação Científica, Tecnológica, Artística e Cultural - XXXVI JICTAC/UFRJ - 2014). Therefore, the result shows its suitability for the development of the experiments.



a) b)

Figure 6. Wind tunnel mapped into 5 sections [a] and 16 points in each section [b]. Source: Henrique Drach images.

Four different methodologies were checked for experimental simulation in WT viewing: with tapes, with wool yarn, with the technique of eolic erosion, and smoke. The techniques of tapes and wool yarn were applied to architectural models and the techniques of eolic erosion and smoke were applied to the urban model.

4.1. Visualization Techniques

4.1.1. Visualization with tapes

The technique with the tape was used to make the visualization of the wind path inside the housing module. The image in Table 2 line 2a shows the reduced model positioned in the test table. For better observation, during the experiments, this was positioned on a white background because the tapes used were dark in color (cassette). In this case, the tapes were attached, only at one end of the opening, corresponding to a gate, and left free inside the environment. Then the tunnel was connected and the direction taken by the tapes can be observed. The experiment was repeated for other arrangements of openings being possible; changes can also be observed in the distribution of the set of tapes within the module.

The first experiment was conducted with openness to sota-wind in the same direction of the port on which the tapes were held. The images in Line 2 (a and b), show that the tapes followed almost straight towards the opening indicating little wind distribution within the module. The introduction of two openings in sota-wind did not cause observable changes in the distribution of the wind inside the module (Line 2, c and d).

Table 2. Sequence of images for the experiments: Line 2 - with openings to sota-wind direction and exit door at windward. Line 4 - cross ventilation. Source: Henrique Drach images, Drach and Corbella, 2010.

a	b	c	d
			

a	b	c	d	e
				

The other change made was to obstruct the passage sota-wind towards the door in which the tape was stuck. The result was significantly different, and can be seen in the sequence in Table 2 Line 4. The tapes occupy the inside of the model presenting a wave motion in conjunction with changes between the expansion and retraction actions. The images were taken in the order presented, observing shrinkage in the image on Line 4d and again expanding in Line 4e, or the dynamics of the wind field can be represented.

This technique allows a good view of the whole, especially with the use of the white background. The tapes are flexible and offer no resistance to touch the walls and edges of the reduced model.

4.1.2. Visualization with wool yarn

To allow visualization with the wool yarn, a trolley that slides inside the tunnel was developed, allowing wool yarn to approximate the model without the direct interference of the experimenter. Thus, the wool yarn is free to enter or not in the set, having the path determined solely by the wind direction.

The cart for the wool yarn is made of wood and has wheels so one can slide it inside the tunnel. To this end, wooden rods are fixed at their base, allowing it to be pulled or pushed in direction of the model, and altering the positioning of the wool yarn to near or far from the model (Table 3 Line 2). In its sides, there are points for engaging the horizontal bars, in which wool yarns are fixed. There are three bars, adjusted to different heights (Line 2a), where the wires with different colors are fixed; the red wires are fixed on the higher bar; the orange wires are positioned on the central bar; and the yellow wires are on the lower bar. With these differences, it is easier to associate where the wires are inside the assembly. In Line 2b, the habitational model appears willing on the test table and the cart for the wool yarn is positioned to start the experiment. To model a transparent coverage ceiling acrylic was used. In the images from Line 2c and 2d, the results are obtained with the openings aligned to the windward and leeward wind can be observed.

Table 3. Table of tests and cart wool yarn (a) positioned (b) module and test with wool yarn: openings aligned to the windward and leeward wind (c - d). Source: Henrique Drach images [2].

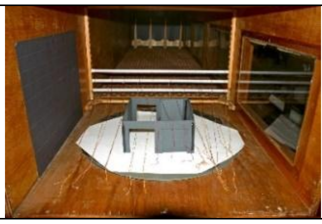
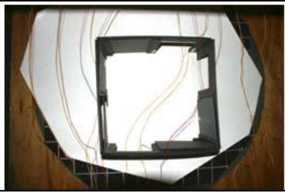
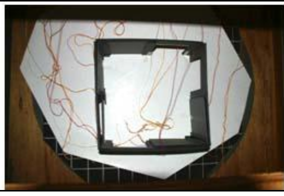
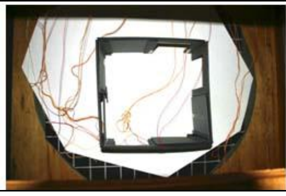
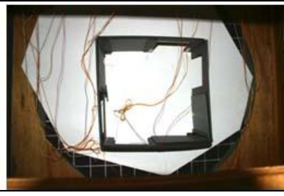
a	b	c	d
			

Table 4 shows the set of images of the experiment with an opening on the windward side, an opening in the leeward and producing a cross ventilation. Finally, it is possible to observe an additional lateral opening.

Table 4. Wool yarn: set of images of the experiment with an opening to windward, and another leeward wind resulting on a cross ventilation system. Source: Henrique Drach images [2].

a	b	c	d
			

From these results, it is possible to notice changes in the configuration of the wool yarn from the alterations imposed on the model. Although it is not possible to perform quantitative analysis of these results, it can be assumed that qualitative measurements are possible, for example, determining whether a configuration of apertures resulted in a more or less intense ventilation. The wool yarn, despite showing good visualization and being easy to use, has to be changed frequently because when the old one can present some grip when in contact with the material of the model.

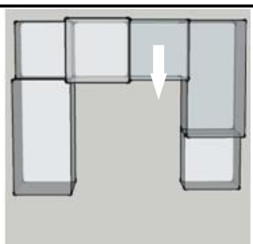
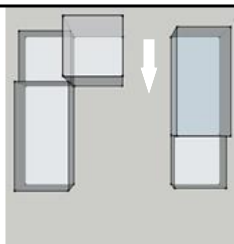
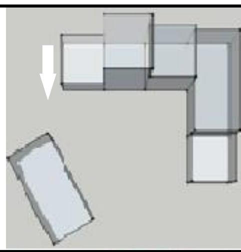
4.1.3. Eolic erosion or sand-drag technique

The technique of eolic erosion (or "dragging sand") can be of great help in understanding the paths that the wind takes in the urban environment, as well as their entries and possible barriers (6). With this technique, it is possible to observe, in the pedestrian level, vented or sealed, depending on prevailing directions and velocities of the winds. The study of the areas where the sand accumulates combined with the study of solar radiation, allows identifying the possibility of heat island development, as well as areas where pollutants are concentrated.

The eolic erosion consists of applying selected sand on all exposed surfaces of the model and then the wind tunnel is connected. For the experiments using this technique, tests were done to allow the definition of the material most appropriate to the experiment. In the first test of the wind tunnel with an urban model, sand with granulometry of 0.015 mm was used, but this had no significant displacement, even at the highest velocities. Further tests were made with other materials: clay (# 0.0075 mm); sand (# 0.0075 mm); and a new test with sand (# 0.015 mm), talc, and cement. Evaluating the pros and cons of each material in relation to the reality of the facilities of the tunnel, the adoption of smaller sand grain size was determined (# 0.0075 mm), a clear and fine sand obtained with the use of sieves.

The studies on WT/FAU are developed with hypothetical and real space models. The experiments presented in Figure 5 show the results obtained for the hypothetical urban space built with compact blocks and allow immediate observation of changing paths taken by the wind. The experiments were performed in series to allow the observer positioned in WT/FAU laboratory to do immediate visualization of the changes drawn in the sand for the three scenarios. Altogether they form the big "U" (Table 5 column a) where the accumulation of sand inside the joint because of lack of wind is noticeable. To promote ventilation in this place, in Table 5 column b, one of the blocks located upwind was removed allowing wind access to the interior of the joint, resulting in a new setting of the deposited sand. Table 5 column c presents the rotation of one of the sidewall plates, consequently showing a change in the distribution of sand in the base of the profile structure. In all three images, the wind direction is indicated by the arrow and less ventilated regions appear outlined, confirming that the dynamics of the wind varied only by changing the positioning of the blocks.

Table 5. The deposit of sand for each case indicated by a frame showing the least ventilated areas [2].

a	b	c
		

The results obtained for the hypothetical urban space with compact blocks, allow immediate observation of changing paths taken by the wind. The experiments were performed in series and allow the observer positioned in the laboratory of the wind tunnel the visualization of the changes drawn in the sand for the three situations. The observers in the wind tunnel room are invited to suggest interventions in the dynamics of the experiment by changing the position of the model or its elements and then observing the effects of their action. This fact distinguishes this type of active observation from that resulting from the presentation of a film or video.

From the experiment and the identification of possible critical concerns, it is possible to point out and test interventions to help fit the adequacy between comfort needs and urban space. Some interference can be suggested for areas where there is no wind according to climatic region in which they are located. For example, in hot and humid climate regions, the need to induce higher ventilation is known. Thus, changes in the shape and position of obstacles, allowing redirection of the wind can be studied to induce an increase in ventilation and improve shading to minimize the problem and prevent the formation of heat islands.

In the case of regions with dry warm weather, besides the need to ventilate, reflecting pools, fountains, among others, that decrease the air temperature through humidification can be adopted. In cold climates, poorly ventilated areas are protected from the cold wind, and so they can be considered places of comfort.

The technique of eolic erosion allows the visualization of wind paths at pedestrian level, and this was applied to urban models. The model was first tested to that formed by a compact set of blocks of varying sizes. These blocks allow the set to be organized according to what one wants to evaluate; therefore, they may be lined, diagonal, overlapping, or even following special settings. The second urban model tested was the Largo do Machado Square, located in the neighborhood of Catete, South area, in the city of Rio de Janeiro. In Table 6, the sequence can be observed with the results of experiments to Largo do Machado, a square that although situated in a densely occupied region, seems to have satisfactory levels of ventilation.

Table 6. Sequence of ventilation in urban space: model of the Largo do Machado square (Line 2) and details (Line 3) – [2].

a	b	c	d
			
			

From Table 6, it is possible to observe clearly areas ventilated or not from inside the urban complex according to the prevailing wind areas. Using the WT/FAU, it is possible to test winds from different directions, simply by rotating the test table of the wind tunnel and by positioning the model to receive the desired wind direction. This study provides the best arrangements of the sets for different times of the year, suggesting the insertion or removal of obstacles in accordance with the need to ventilate a more or less specific region. These choices can allow the increase of environmental comfort for each case and improve the quality of the air breathed.

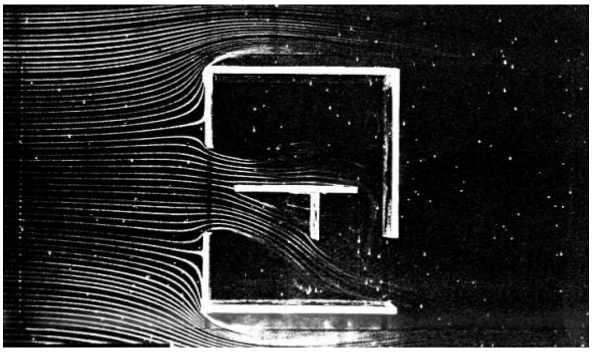
Experiments with eolic erosion allow a qualitative analysis of ventilation in the pedestrian level. In these experiments, visualization of ventilation inside the buildings as well as in the higher levels of studied area was not checked.

Recognizing the ability of interference, even simple interventions, changes in wind fields, tools to develop projects that balance the needs of users can be had, thus reducing energy consumption and pollution.

4.1.4. Smoke technique

The experiments related to viewing through smoke in the wind tunnel at FAU are still in the process of improvement. The development of research on natural ventilation in the world has been producing important advances in teaching ventilation. Authors such as Liddament [7], Santamouris [8], Allard [9], and CIBSE [10] contributed to building a solid theoretical framework and guide capable of leading the student through the path of learning. The development of visualization techniques is of paramount importance because it is a form of perception usually immediate and impactful for students of architecture and urbanism.

The classic experiments presented by Olgyay [11] with simulations of reduced models, as the examples in Figs. 7a and 7b, are not easy to reproduce. For the formation of long and defined fillets of smoke, numerous adjustments are needed, and some of them are the smoke components, dimensions of the ejector nozzle, distance and caliber of the tubes that carry the smoke, calibration of the relationship between speed in the tunnel and the speed of the smoke, among others. It is worth remembering here that the experiments conducted within the WT Laboratory at FAU/UFRJ should take into account the presence of students in the room where the experiments are performed and therefore, care must be taken to prevent risks to students. The smoke components should not contain toxic elements.

 a)

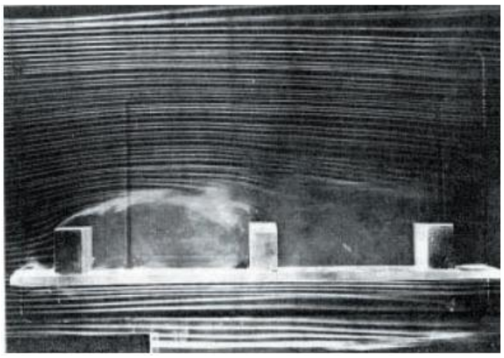
 b)

Figure 7. Flow visualization – architectural [a] and urban [b] models. Source: Olgyay 11, pages 107 and 101, respectively.

The technique for qualitative airflow visualization with smoke presents encouraging results with the observation fillets continuous smoke. To obtain this longer fillet, an expansion chamber coupled to the set of equipment for smoke generation interconnected by a fan was used. Developed nozzles were tested to identify the desired flow. In Fig. 8, the equipment for smoke generation is shown (Fig. 8a); the fan (Fig. 8b) that was coupled to the system to provide greater velocity and pressure to smoke before this reaches the nozzles (Fig. 8c) and the expansion chamber (Fig. 8d)

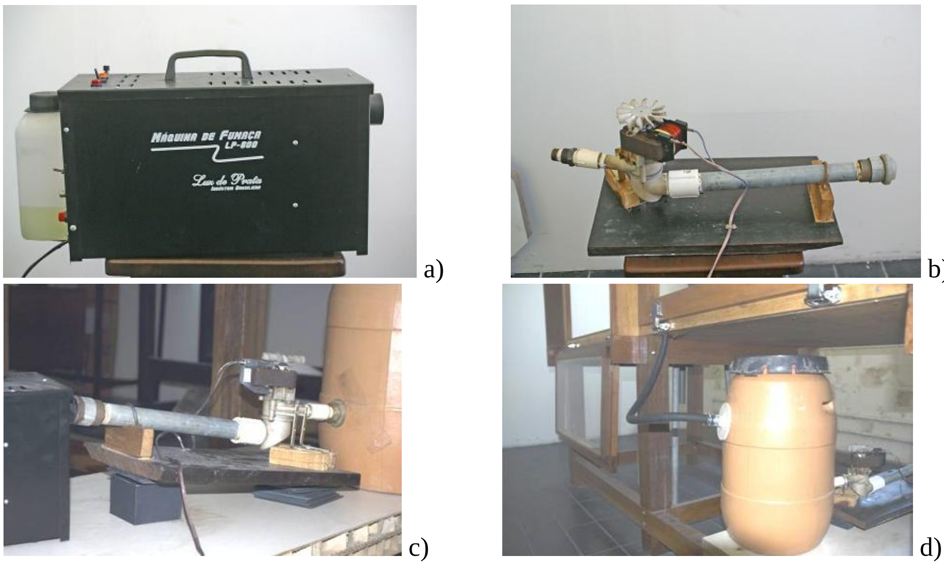


Figure 8. Equipment for smoke generation [a], a fan [b] mounted assembly [c] and tube [d]. Source: Henrique Drach images.

The images from Figures 9 and 10 show the sequence of smoke generated by the set; smoke machine, fan, expansion chamber, and pipe leading smoke to the nozzles. The continuous trickle of smoke is also seen in the images. The photo in Figure 9a shows the smoke lines coming from the injection nozzles.

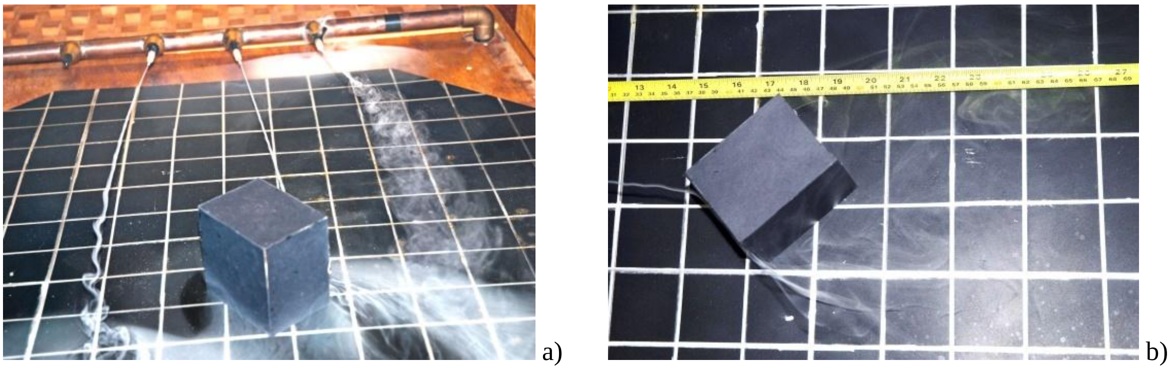


Figure 9. Sequence of images with the smoke line reaching the block. Source: Henrique Drach images.

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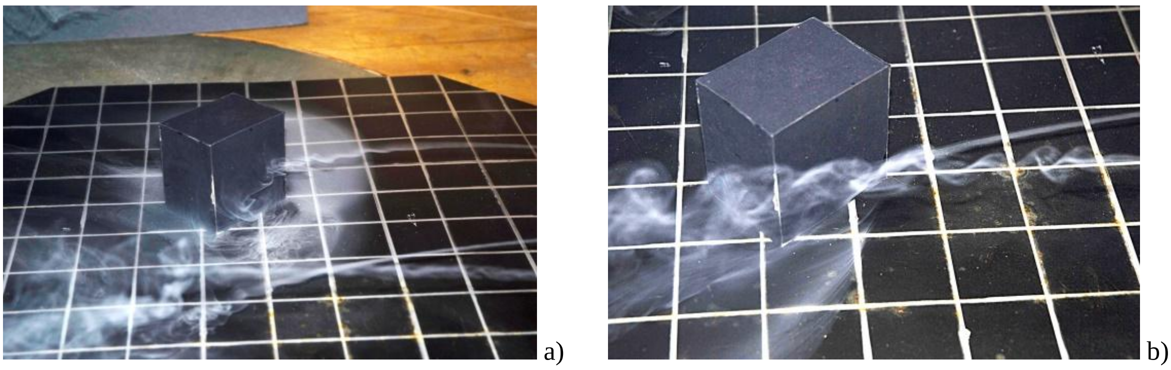


Figure 9. Sequence of images with the smoke line reaching the block. Source: Henrique Drach images.

When the smoke line reaches the block (Figure 9b, 10a, and 10b), the movement of air immediately changes to a turbulent one, making it possible to observe the effects of the barrier redirecting the flow.

Some changes have been checked aiming to improve the visualization of the smoke to make possible the total registry of the sequences, by photos and films. One way could be by testing different colors and lighting systems inside the wind tunnel and on the blocks.

V. Feedback from the students

Because of the didactic character of the research developed in WT/FAU, it is important to know if the experiments are clear enough or able to stimulate the minds of the students to develop their own project with this aid tool.

Thus, after the activities, visitors are invited to fill out a questionnaire whose answers can improve the process of submission, review of the methodology, and development of new experiments.

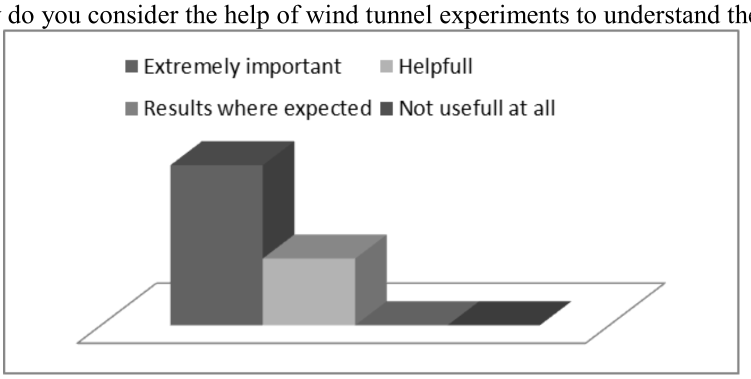
These questionnaires are analyzed and transformed into results to infer the relevance of the experiments for students in their understanding of the ways of the wind. The vast majority of students (93%) had no idea of the possibilities of working with wind tunnel (WT/FAU) as a design tool, and indeed, they were surprised with the ability to view and with the power of direct interference in the ventilation of the architectural and urban spaces, even by just adopting simple changes.

Thus, after the activities, visitors are invited to fill out a questionnaire whose answers can improve the process of submission, review of the methodology, and development of new experiments.

These questionnaires are analyzed and transformed into results to infer the relevance of the experiments for students in their understanding of the ways of the wind. The vast majority of students (93%) had no idea of the possibilities of working with wind tunnel (WT/FAU) as a design tool, and indeed, they were surprised with the ability to view and with the power of direct interference in the ventilation of the architectural and urban spaces, even by just adopting simple changes.

When we asked "How do you consider the help of wind tunnel experiments to understand the wind paths?" - The chart bellow shows that 71% of the students considered the tool to be of paramount importance while 29% considered it to be helpful in some meaningful way (Chart 1). Observing the experiments on the wind tunnel was considered helpful to the understanding of ventilation and its properties.

Chart 1. "How do you consider the help of wind tunnel experiments to understand the wind paths?"



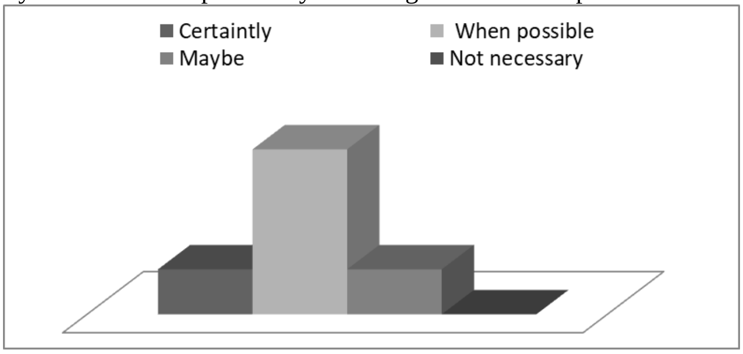
According to investigations, many of the students considered the contribution of this important tool to understand questions related to the wind and its effects, and some return to experiment with their own models. In addition, individual experiments were performed with the help of assistants, even with exchange students, where they are able to test their own models to display urban wind effects in Rio de Janeiro city.

The results show that 65% of the pooled students considered that the experiments positively contribute to their academic training as well as to their understanding of environmental comfort, since the visualization of the wind paths enables them to better understand wind dynamics in both urban and architectural projects.

It is also worth mentioning that 66% of the participants declare that they consider the possibility of testing their future experiments in wind tunnels.

Chart 2 shows that 17% of the pooled students say that they intend to make models of their future projects in order to test them in wind tunnels.

Chart 2. "Do you consider the possibility of testing their future experiments in wind tunnels?"



Despite their original commitment in testing future projects it is observed that less than 66% actually do it. This inferior return rate – when compared with the declared intentions of students – can be explained to some factors, among which it is worth to emphasize: 1 - time restrictions, as this student, now professional architects, are under constant pressure to produce as much in as little time as possible; 2 - the lack of availability and will to construct models, a prerequisite to testing in wind tunnels. However, the impact of the usage of models in wind tunnel simulations is clearly visible, sometimes leading to small changes in the original project that generate profound impacts in the quality of the outcome.

VI. Conclusion

The didactic visits of students to the WT/FAU make possible the knowledge of the possibility to adopt it as a projectual aid tool. The space is open for students to bring their models of projects to be tested.

For this, it is necessary to respect the dimensions of the test table in the construction of the model and bring the data side of the prevailing wind and winds of the project site. Observers in the wind tunnel room are invited to propose interventions in the dynamics of experience. They are able to interfere by changing the position of the model or of its elements, testing configurations that best suit the project and the characteristics of the place. The results of the effects of their decisions can be observed immediately and from there, it is possible to review the ideas in a dynamic feedback mechanism so that the most appropriate option is determined.

The observation of these results, in person or through images, contributes to the practice of various disciplines of courses related to the production of spaces because it allows the immediate identification of the paths taken by the wind and the interference level that even simple obstacles can offer in the different areas.

The experiments conducted on the WT FAU/UFRJ meet the objectives of producing documentation, ease of view, and paths taken by the wind in architectural and urban spaces.

The technique using the tapes is easy to implement and provides a good visualization of the wind action inside the model, especially with the use of the white background. The tapes are flexible and offer no resistance to touch the walls and edges of the joint, and allow good visualization of the wind effects.

The trolley with the wool yarn worked as expected, namely, allowing the alignment of yarns in relation to the openings of the module without the direct interference of users. It was possible to observe the ways of the wind inside the joint and the flow changes induced by position openings alteration. The use of colors in layers with three different heights also helped the viewer in understanding the ways of the wind.

The technique of eolic erosion used for urban spaces allowed the observation of the windpaths and the implications of the changes imposed on the set of compact blocks. The observation of these changes immediately helps students and professionals understand the importance of interference and their ability to make design decisions. The experiments allowed the observation of the wind field and the identification of best-ventilated areas in the square, assisting in future interventions aimed to improve this environment. The results may help define strategies for urban planners and landscape architects, to design spaces, especially of public use, where the residence time is longer, minimizing undesirable situations.

File stills, movies, and videos containing the unfolding experiments can be produced and can be of great help in classes and lectures. Experiments with different configurations can be tested for squares and even blocks allowing identification of the most suitable arrangements for each location. These files can serve as "initial guides" for some design situations.

It is important to invest in training professionals able to recognize the importance of ventilating the city and the need to make choices that achieve reasonable levels of environmental comfort, especially in warm countries.

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