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THE USE OF CFD APPLIED TO STUDIES OF VENTILATION IN URBAN AREAS IN CAMPINAS, BRAZIL

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ABSTRACT

The aim of this work is to discuss the effect of urban block and lot design in natural ventilation of self-built houses in the city of Campinas, Brazil. The research was carried out with CFD simulation, using the software PHOENICS to calculate air velocities in the external regions of the residences. The case study was a surrounding in the city, the settlement São José, which was urbanized by the public organs having in mind low-income self-builders. The houses were analyzed through results of two surveys: one in the years 2000, which characterized the self-built houses, and the second one in 2005, to verify the modifications and their consequences in the environmental performance of the houses. Results show that poor natural ventilation is due to the lack of information about the prevailing winds, orientation problems and the modifications carried out by the self-builders.

INTRODUCTION

In Brazil, as in many developing countries, spontaneous housing is synonymous of extreme conditions of poor quality housing and has a negative impact on the urban environment. Due to specific local urban growth patterns as well as to economic and social structures of the country, self-built houses, that is, houses built by owner families, make up a substantial percentage of Brazilian housing production, around 60% (Oliveira et al, 2005). Due mainly to low quality design solutions, self-built houses present on the whole a low environmental comfort standard

The housing groups of social interest of the city of Campinas, Brazil, are composed of uni-familiar houses or multi-familiar units in residential groups up to five floors. In these groups, the implantation usually follows the pattern of the urban design based on the orthogonal mesh and in a simple repetition of identical units. In Campinas, the Housing Company of City Government (COHAB) provides lots for self-builders in the outskirts of the city. In some cases, the lots are provided with a small three-room house, the so-called embryo-house, and the owner goes on to finish the house, modifying the built area. The legal status, achieved through the acquisition of a lot, creates expectations, not always possible to be fully realized by these low income families. Lot dimensions are small, with a geometry that limits design possibilities. Lots are mainly rectangular narrow strips of land, to reduce street front dimensions and thus subdivision infrastructure costs.

Often the subdivision layout is not ideal for the siting of desirable house designs. Orientation of streets does not take into account sun exposure and ventilation conditions. There are three types of self-built houses which characterize the implantation of self-built settlements: a) house built in the back of the lot, b) along most of the side walls; c) in the centre of the lot.

Due to the poor quality and small size of the houses, there is a constant reforming activity of self-builder owners with the aim of enlarging the house, to accommodate more family members, to assure security for the inhabitants, and to house the family car.

The modifications implemented by owner-builders in the houses show design alterations both horizontal and vertical. Horizontal modifications are the garage roofs, constructed to house vehicles. Vertical ones are those due to the construction of walls and fences.

Simulation through CFD is a powerful tool for studies about natural ventilation. They are useful for the numerical calculus or for the visualization of the wind flow indoors and outdoors. There are many softwares that define fixed values for pressure coefficients, as well as for turbulence. These fixed values come from empirical models, based in wind tunnel studies. The presented analysis in such cases defines internal and external flow lines.

The aim of this research is to quantify the positive or negative effect of the most common modifications in the façades of self-built houses on natural ventilation of the houses, through CFD simulation. The software used was PHOENICS 3.6. A methodology is proposed for the study of natural ventilation in urban lots in the city of Campinas, Brazil, with input parameters data values of wind velocity and direction, obtained at INFRAERO (Brazilian Company for Airport Infrastructure) for the period from 2000 to 2005. The adopted model used the standard size of a typical block in the settlement São José, a typical self-construction settlement in the city.

SIMULATION

The Phoenics 3.6 CFD program was used in this research. The turbulence model was the modified k-ε model by Chen & Kim(1987). This model includes an extra time scale in the ε equantion and several coeficients are adjusted to maintain the good agreement with classicall experimental data. This model is activated by keyword *KECHEN* in the *PHOENICS* program (LUDWIG, 2004).

All the objects that will be included in the simulation must be prepared in a step-by-step procedure that defines its attributes. The first step is the definition of the domain size. Wang et. al.,(2007) suggests that, in urban climate CFD analysis, the minimum distance between the studied objects and the boundaries of the domain maintain a certain proportion to the height of the object. From the flow inlet surfaces to the objects, they propose a minimum distance of 8 to 10 times the object height, to the flow outlet surfaces a minimum of 8 times the height and that the height of the calculation domain is at least 6 times the object height.

The simulation was done in two different stages: surrounding urban area and the specific characteristic block. In the first step, the simulation model contained many blocks, including the characteristic block, and the immediate surroundings. The model was defined by a calculation domain with the size of 800m, 400m and 70 meters in directions x, y and z, respectively. The mesh contained 125 subdivision in the x direction, 56 in y direction and 100 in z direction, resulting in 700.000 cells in a Cartesian coordinate system. An upper view of the mesh can be seen in figure 1. It can be noticed that the mesh spacing is gradually varied using a geometric progression. The larger mesh spacing is about 20 m in the flow inlet region and the smaller spacing is about 1 m in the regions near the houses.

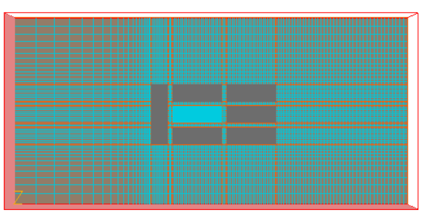

Figure 1 The created mesh with the studied characteristic block appearing in the Center.

The boundary conditions were applied in the six faces of the domain: two flow inlet faces, two flow outlet faces and the lower and upper faces.

The wind speed and direction measured by INFRAERO, was inputted in the WRPLOT VIEW program, which calculated the hourly medium velocities and directions. It can be seen the strong predominance of southeast direction.

The material properties are selected in the “object” dialog box. Air was considered to flow without exchanging heat around concrete buildings, whose properties are shown in table 1.

The convergence of the calculations was carefully assessed. The convergence criteria suggested by Ferziger and Peric (2002) was used. According to these authors, the value of the residues obtained after a number of iterations can be compared to the residues of the first iteration to assess convergence. A reduction of the residues of about three to four orders of magnitude is recommended.

In the second stage, the calculation domain is reduced, including only a region containing the characteristic block. The flow inlet velocities used in this stage are the ones obtained in the first stage of the study.

The objects used for establishing the boundary conditions are modified only in the two flow inlet surfaces and depend on the values obtained in the first stage. To obtain the velocities in the entry cells that were located in the vertical planes directed to the SOUTH and EAST directions, an interpolation was made using the data of the first part of the simulation

With this intent, a program was written in C language that reads the data of the first stage of the simulation, interpolates the data, and writes a file that contains a series PHOENICS commands that establishes the boundary condition in each entry cell. The executable program was generated using the DEV-C++ compiler.

In part 2 of the simulation, the file with the commands is read by PHOENICS, which executes them. The file has 33179 lines containing PHOENICS commands.

Since in the second stage the flow inlet velocities are obtained from the first one, there is no need to use the WIND-PROFILE object, that was used to establish the boundary conditions in the first stage of the study.

The insertion of the characteristic block is done by the stlout command of PHOENICS, that imports the three dimensional drawing of the block created in CAD.

The characteristic block is formed by residences that were modified between 2000 and 2005, for comparison. The block contains models of the residences according to their design of the years 2000 and 2005. To obtain these data a survey was made with all residences in the neighborhood in those years Figure 2 shows the same residence depicted in 2000 and 2005 respectively.

Figure 2 - Residence depicted in São José neighborhood at different times, on the left in 2000 and on the right in 2005.

The residences were visited and their plan was drawn. Figures 3 and 4 show the plan of the residence of figure 3 in 2000 and 2005, with the modifications that occurred in the period.

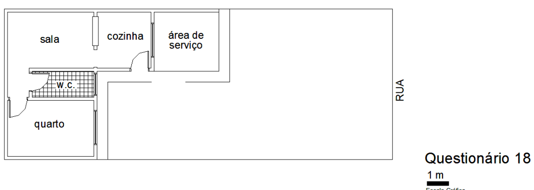

Figure 3 Plan of the residence of figure 2 as observed in 2000.

Figure 4 Plan of the residence of figure 2 as observed in 2005.

In the whole it was done a survey with 13 houses randomly chosen in the São José neighborhood resulting in the standard block shown in figure 5.

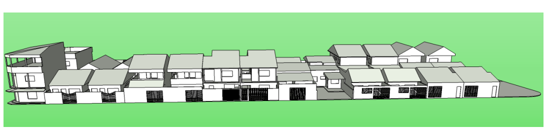

Figure 5 The characteristic block used in the simulation, the house of figure 2 corresponds to the 8^{th} and 9^{th} houses, from left to right.

RESULTS

Figure 6 shows a topview with the calculated velocity values in the horizontal plane at 1m height above the ground.

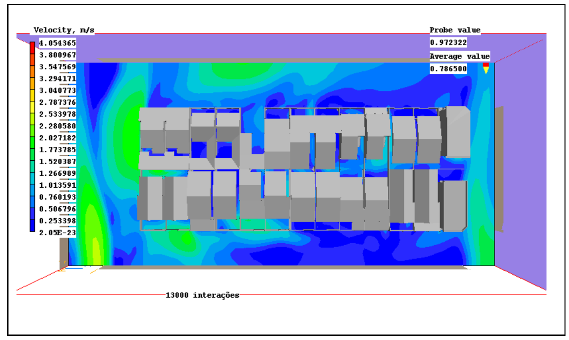

Figure 6 Upper view of the model implantation

A total of 26000 iterations were done. With this number of iterations the reduction of the residues was five to six orders of magnitude for all variables except for wind velocity in direction z. The residues for this variable are very small at the start of the iterations and then they increase, since the final residues are four orders of magnitude smaller than the maximum residues it was considered that convergence was attained because fully the criteria of Peric e Ferziger, 1990 was accomplished with a substantial margin of safety.

Part 2 of the modeling can be analyzed in a first stage under the aspect of the insertion of the block in the urban area. Part 1 of the modeling stipulates that wind speed in urban area is under 2,5 m/s, for an average speed of about 4 m/s in the city of Campinas. The highest velocities, between 0,9 and 1,4 m/s occurred in houses 12 and 13, in the corner of the predominant flux.

Houses with façades oriented to SE (the direction of the prevailing winds) could be more benefited by ventilation if the width of streets and sidewalks was otherwise planned. In the existing reality (6m street width), the recirculation occurs mainly in the corners, which reduces wind speed, so that in the houses lots, it is not higher than 1 m/s. Figure 7 represents the streamlines that originate in the first cell of each lot, at the height z=1m, for the houses facing prevailing SE winds.

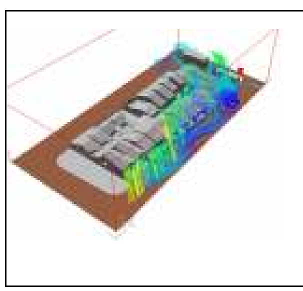

Figure 7 Streamlines for houses facing prevailing SE winds.

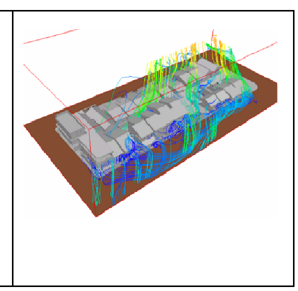

Figure 8 Recirculating wind flow in the street, consequence of the houses facing west.

Houses facing east receive greater influence of the recirculation (vorticity) effect produced by the 6m street width in this neighbourhood. In the west side, as shown in figure 8, the recirculation in the streets results from the flow passing through the houses facing west.

Figure 9 shows the resulting streamlines originated in the first cell in each lot, for Z = 1m, both for east and west façades. The urban design of the settlement São José, for low-income housing, does not allow blocks with four facades, only two, a common feature in Brazilian urban settlements. The most important factor considered in settlement design is the topographic leveling. Wind profile is usually not taken into account.

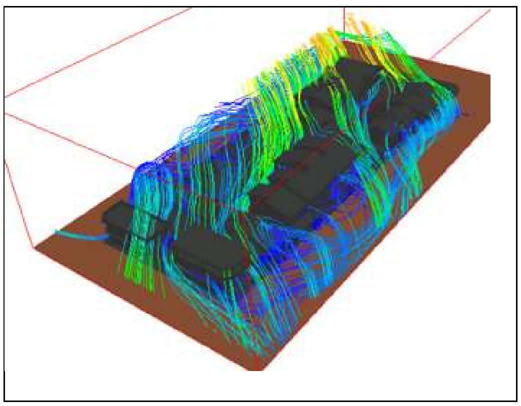

Figure 9 Streamlines originated at east and west façades.

In the results, it was observed that in four residences the wind flow was reduced, in two the flow was about the same and in five there was an increase of wind flow inside the terrain. It was also observed that the position of the houses in the block affects the wind velocities. Some houses that were not modified had their wind flow changed due to the other houses and the pattern of the surroundings.

To demonstrate the results obtained, figure 11 presents the results for the two plans of the house shown in figure 2. The two side by side houses correspond to the plant of 2005 on the left and the plan of 2000 on the right. The wind speed is also presented in the figure and is measured in a height of 1 m. The values vary from 0.2 to 0.9 m/s

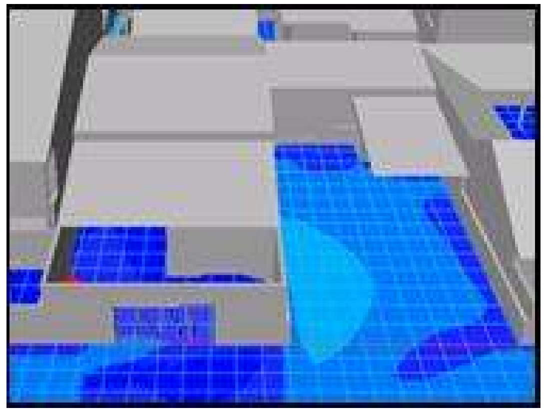

Figure 10 Results for the two plans of the house depicted in figure 2.

Table 1 presents the wind velocities calculated at 1m height at 32 cells of each plan of the house depicted in figure 2. These 32 cells correspond to the eight by four first cells in the front of the terrain.

Table 1: Wind speed(m/s) calculated in the 32 frontal cells

Position		x							
Y	year	2	3	4	5	6	7	8	9
	2005	0,34	0,39	0,44	0,47	0,48	0,49	0,48	0,47
11	2000	0,45	0,47	0,48	0,53	0,62	0,70	0,78	0,86
	2005	0,28	0,31	0,34	0,34	0,33	0,35	0,42	0,50
12	2000	0,47	0,54	0,58	0,63	0,69	0,75	0,82	0,89
	2005	0,20	0,21	0,23	0,23	0,24	0,30	0,41	0,50
13	2000	0,50	0,57	0,63	0,68	0,72	0,78	0,83	0,91
	2005	0,24	0,23	0,22	0,20	0,21	0,28	0,39	0,44
14	2000	0,47	0,57	0,64	0,69	0,73	0,78	0,83	0,91

In table 4 it is noticed that wind speed has decreased in the frontal part of the terrain which results from the increased wind obstruction caused by the additional walls and accommodations that were built.

DISCUSSION

Simulations were largely studied so that it could be reached a final result with the best possible exactitude. It is important to state that PHOENICS is a very complex software, but the insertion of data was fulfilled with the best clearness possible.

Low wind velocities and the tendency of wind to follow its natural flow contribute to the creation of vortices in almost all free areas in the interior of individual lots. This contribution comes even from side corridors, which act as natural wind catchers, from which the wind reaches larger areas.

The slope orientations of the roof also interferes with orientation and velocities of air flows; two-slope roofing, with slopes oriented to the front façades also can contribute to air recirculation in the lots. This was not the main objective of this work, but this aspect should be considered in future studies.

The small size of standard lots and the needs of the self-builder population are a reality in Brazilian low-income housing settlements. So it is worthless to propose that one of the possible solutions for ventilation problems in these houses is to avoid the building in one side of the block, or the vertical and horizontal modifications of the original houses.

But design recommendations both for public organs, in the early stages of the new urbanization areas, and for the self-builders are possible and important. These recommendations refer to direction of prevailing winds, orientation to the sun, with blocks facing north-south instead of east-west.

To owner-builders, the recommendations refer to relation between gate and/or fences, external walls, side corridors, roofing slope. Special attention should be drawn to the effect of walls in the limits of the lot and garage roof, which affect very negatively the ventilation in the houses, with harmful effects on environmental comfort and life quality of the inhabitants.

CONCLUSION

CFD simulations were performed to evaluate the external natural ventilation in a typical block of self-built houses. The simulation was performed in two stages.

In the first stage the far field in the surrounding area was studied. In this first model it was verified that the urban design in settlement São José reduces wind velocity to values between 2,0 and 2,5 m/s in the local streets, as a consequence of a far stream wind velocity of 4m/s.

In the second stage the typical block was studied creating a model with 26 houses found in the settlement, randomly selected, as well as the occurred alterations (or not), in a period of five years. The observations of the simulated block as a whole allows noting that interrelationship between houses is of fundamental importance to assure good ventilation, and that houses facing opposite to prevailing winds receive undesirable odours and impurities from neighbouring dwellings.

The results show values between 0,1 and 1,2m/s for the wind velocity in the external region surrounding the houses. The greatest values are found in the corner houses, were there is a stronger incidence of winds.

The analyses of ventilation in self-build houses through CFD simulation in the settlement São José enlarged the knowledge about natural ventilation in urban areas as altered by self-builders. The proposed methodological tool for simulation shows the problems resulting from this constructive model and how it reflects in natural ventilation of the area.

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