Evaluating natural ventilation in multi-storey social housing:
case studies in Campinas, Brazil.

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ABSTRACT: This article aims to discuss the internal natural ventilation in multi-storey social housing buildings aiming to achieve users thermal comfort. These houses are built in the context of the Brazilian Housing Program "My house my life". This program is in its second phase and aims to reduce the housing deficit in the country through the construction of 2.4 million homes by 2014. Since Brazil is a country with a hot climate, it is known the importance of using passive cooling strategies to obtain thermal comfort and reduce energy consumption. For this analysis simulation through specialized CFD was used. Two different architectural typologies (type "H"and rectangular plant) of multi-storey buildings in the city of Campinas, southeast of the country, are compared. These typologies are recurrent in almost all regions of the country, regardless of local climate. After the plant selection, three-dimensional models were built considering the existing openings for ventilation of the apartments (all apartment windows and doors completely open, except the entrance door). The wind database for the city - direction and speed- corresponds to the period of 9 consecutive years (from 2001 to 2010). Qualitative results (images of internal airflow) and quantitative ones (average indoor air velocities) show that such factors as implantation of the building in relation to the prevailing wind, formal symmetry, position and size of openings and internal distribution of rooms impact directly on internal ventilation conditions of the housing units. These are design factors defined in the early design stages.With these results it is expected to contribute to improve the quality of new similar projects, where natural ventilation should be prioritized, thus allowing to achieve thermal comfort for users particularly on these plant types.

Keywords: natural ventilation, CFD simulation, multi-storey social housing, thermal comfort.

INTRODUCTION

Since the confirmation of the world's energy crisis, architecture has been playing an even more important role, since designers can predict through the correct utilization of natural resources, not only more comfortable and healthy buildings, but also energy efficiency. Therefore the use of passive cooling strategies should be the starting point when dealing with projects suitable to hot climates such in Brazil. Natural ventilation is a consolidated resource (or project strategy) for direct and low-cost solution that brings numerous benefits, since in most cases well-ventilated buildings do not need mechanical air conditioning [1].

This article discusses the use of natural ventilation in social housing projects, specifically those belonging to Brazilian's federal government program "My House, My Life" – MHML. The housing deficit in Brazil has always been of huge proportions, so the government is committed to accelerate the solution of this problem through housing programs intended for low-income population [2]. In 2009, former president Luís Inácio Lula da Silva launched the MHML program, which has a large social impact, offering means for low-income families to purchase their so dreamed for a long time "house of their own". MHML is currently in its second phase (from 2010 to 2014), as announced by currently President Dilma Roussef, with the new goal of building 2.4 million homes throughout the whole country. Thus, the importance of evaluating the quality of such edifications is evident, since the population for which these houses are intended cannot afford to pay for design errors, that elevate energy consumption and compromise thermal comfort.

Although aware that each region of Brazil belongs to a different mesoclimate with specificities that determine differentiated project characteristics, what we see in everyday practice is the repetition of the same housing project in many different locations. This happens mainly because contractor companies use the same architectural project for all Brazilian regions. Another question is that the deployment of the blocks within the lot is almost random, since these companies, aiming to maximize their profits, adopt as parameter only the final goal of locating the maximum number of blocks per glebe. Therefore important design requirements are forgotten, such as optimal-efficiency block implantation according to the prevailing wind flows, which confirms that natural ventilation is not treated as a priority in these buildings.

Thus the aim of this work is to verify the quality of two architectural typologies used on the MHML program from the natural ventilation point of view, having in mind to alert mainly designers about the consequences of their project decisions in the users' thermal comfort.

2. METHODOLOGY

2.1. Selection and characterization of case studies in Campinas

The MHML program in Campinas began in 2009, and in the next year, the number of constructions approved in that city was already considered too big. In order to explain the program's implementation, the city government made available on its internet webpage all the information about vacant building sites, approved projects, quantity of available units, construction finishing schedule, and everything else about the MHML program in Campinas.

The main criterion for selecting the constructions suitable for case studies was the social impact. So, we selected those with approximately 2.000 housing units (that's the reason why we opted for multi-familiar edifications), and within the income spectrum of 0 to 3 minimum wages, which corresponds to the low-income population.

Case study 1 is located at Parque São Bento residential complex, at Campinas' southwest macro-region. This construction has a total of 2.380 housing units distributed in 119 blocks. Its floor plant is shown in Figure 1. Each block has 5 stories (the ground floor is considered the first one). The construction was completed at the end of 2011.

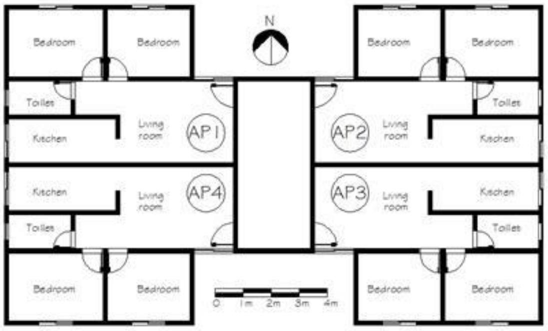

Figure 1: Floor plan of the case study type 1

Case study 2 is located at Campinas' south macro-region, along the Anhanguera SP-330 highway. The whole complex has 2.120 housing units distributed in 53 blocks; the contractor usually builds blocks conjugated two by two with geminated walls, which results in eight housing units per story, as shown in Figure 2.

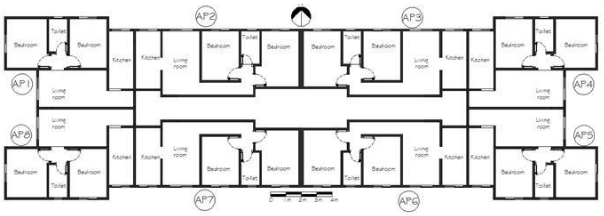

Figure 2: Floor plan of the case study type 2.

2.2. Characterization of winds in Campinas/SP

The wind characterization is necessary because we needed to create a scenario close to reality in the computer simulations. The station used belongs to Agronomic Institute of Campinas – IAC's meteorological station, located at Fazenda Santa Elisa (22°53' S latitude; 47°5' W longitude; 664 m altitude). This station is located next to one of the studied constructions (case study 2), and with similar rugosity characteristics (i.e., located on a suburban region).

For this characterization, the station provided air speed data from 2m to 5m high, as well as the wind direction. The data were daily and hourly, for a period of nine consecutive years (from 2001 to 2010). In order to utilize wind data from 10m high (standard height used by other authors), we corrected the data using the logarithmic equation of wind profile as shown in Eq.(1) [3].

$$U(z) = U\,(zref)\,\frac{ln\left(\frac{z}{z0}\right)}{ln\left(\frac{zref}{z0}\right)} \qquad (1)$$

Where:
$U_{(z)}$= speed at desired height;
z = desired height (10m, in this case);
$U(Z_{ref})$= speed at reference height (2m height);
z_0= region rugosity (0.5m for suburban area).

After correcting the speed values to those at 10m height, we determined the winds' predominant direction. We verified that Campinas' annual predominant wind direction is south-east, with 9 months a year in evidence, and north for the remaining 3 months.

The next step was to determine the total average speed for each direction. To do so, we organized the average monthly speed values in these directions, and by extracting the twelve monthly averages, we obtained the annual average. So, the data used for ANSYS CFX simulation were: south-east direction with average speed 3.59m/s, and north direction with average speed 2.64m/s. We also investigated the east direction, with average speed 2.17m/s.

2.3. Computer simulation with ANSYS/CFX

For this research, we used the CFX 13.0, developed by ANSYS. ANSYS-CFX is composed by four modules in which we can execute simulation steps that range from the model confection to results' treatment. According to Leite (2010) [4], initially, during *pre-processing*, a model is developed from the geometry construction and the domain determination, which creates the model to be adapted in the ANSYS ICEM CFD, an essential CFX module, since it allows the parameterization and mesh preparation that will define the points to be calculated. After this, *CXF-Pre* defines the simulation regimen, which equations will be used in the calculation, the initial and boundary conditions, and the turbulence model. The simulation itself is calculated in the *CFX-Solver*, and the results are visualized through tridimensional images, graphs or tables in the *CFX-Post*.

For manufacturing the tridimensional models, we used AutoCAD [5]. In the models, all windows were considered to be open, as well as the internal doors, with the exception of the apartment entrance door, which, for privacy/security reasons, is usually kept closed. Only effective ventilation openings were considered in the windows. In the kitchens, bedrooms and living rooms, where there are sliding windows, we considered only 50 percent of the frame width. In the toilets, the windows are of the tilt and turn kind, with total opening, so the effective opening area is the same of the window's. Table 1 shows the effective openings for each model.

Table 1: Effective openings of the models (m)

	Case 1	Case 2
Living room	0,7 x 1,2	0,75 x 1,2
Kitchen	0,6 x 1,2	0,6 x 1,0
Toilet	0,6 x 0,6	0,6 x 0,6
Bedroom	0,6 x 1,2	0,6 x 1,2

To obtain the results, three horizontal plans were generated: Plan 1, located at 1.5m above the ground (first floor), Plan 2, located at 6.5m above the ground (third floor), and Plan 3, located at 11.5m above the ground (fifth floor). These heights were chosen because they correspond to the human breathing zone (1.5m above the ground). Apart from internal air flow quality analysis methods, such as vectors, we used a tool called *Isoclips*, that corresponds to a cut in the simulation according to domain parameters (x and y axis distances) provided by the user. After creating the *Isoclip*, the user can obtain information about many variables (such as air speed, temperature, pressure) based on calculations made by us in the tetrahedral mesh of a certain area. This tool was very important in this work, since it made possible the gathering of the air's **average speed** values in each room of each housing unit for the three studied plans (first, third and fifth floors) [6].

3. RESULTS

The quantitative results refer to the average speeds found in each room registered by *Isoclips.* To analyze the average speeds, we established a scale with values in relation to thermal comfort (Figure 3). This scale was developed based on the work of Cândido et al. (2010) [7].

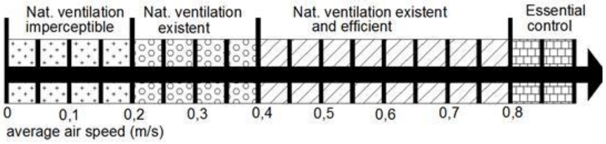

Figure 3: average air speeds in relation with thermal comfort

All the results' analysis are presented for three wind incidence directions: 0° (average speed of the north wind), 90° (average speed of the east wind), and oblique wind incidence (average speed of the south-east wind). Since the studied buildings are symmetric, these three wind incidences allow us to comprehend what happens in the opposite orientations, which gives the designer a general outlook for the positioning of the building in eight different situations according to the wind incidence (0º,45º,90º,135º,180º, 225º,270º,315º).

The results were obtained as follows: from the classification presented in figure 3, results were organized according to the average speeds of each room for the three studied story heights (first, third and fifth floors). Then, we obtained the final diagrams always representing two of the three obtained results. In other words, if in the living room of the first story the average speed found was in the first category, and in the third and fifth it was in the second category, in this diagram we represented the second category for the living room. By doing so, it is possible to give a general outlook of the room's performance for each typology and each wind incidence direction.

3.1. Case study 1

With wind incidence at 0º (Figure 4), only the windward apartments presented cross ventilation. Although formally symmetric, the turbulence generated in the CFD explains the slight difference between the living rooms of apartments 1 and 2. Leeward apartments (3 and 4) are practically devoid of ventilation in every room.

For the 90º incidence (Figure 5), the ventilation efficiency is totally concentrated in rooms that have a direct opening for this position (kitchens and toilets), which function as air inlet (positive pressure zone), and in the living room, which works as air outlet (located at a negative pressure zone). In other words, in these apartments the wind moves from the kitchen to the living room, leaving the bedrooms without ventilation. The simple solution of adopting another opening or even moving the opening of one of the bedrooms to the wind incidence façade would change this result.

At the 135º incidence (Figure 6), we identified a bigger ventilation increment in apartments 2 and 4. In apartment 4, apart the good ventilation in all rooms, it occurs in the correct direction: the wind outlet is through the kitchen and toilet. Even though apartment 3 is in the direct wind incidence, there's practically no pressure variation between its openings, so there's little cross ventilation.

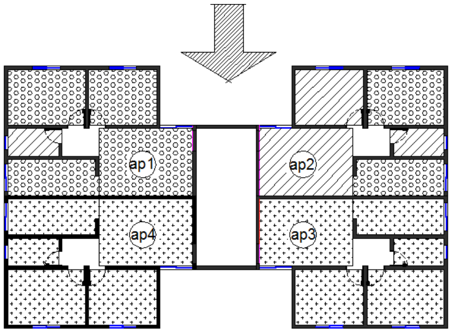

Figure 4: average speeds in case study 1- 0º wind

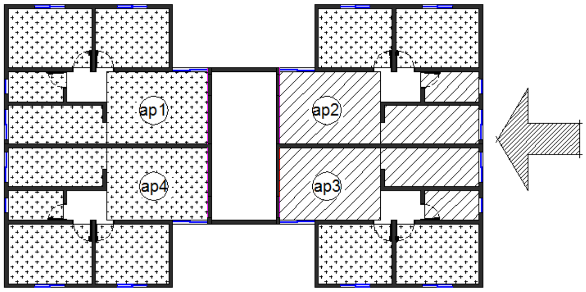

Figure 5: average speeds in case study 1- 90º wind

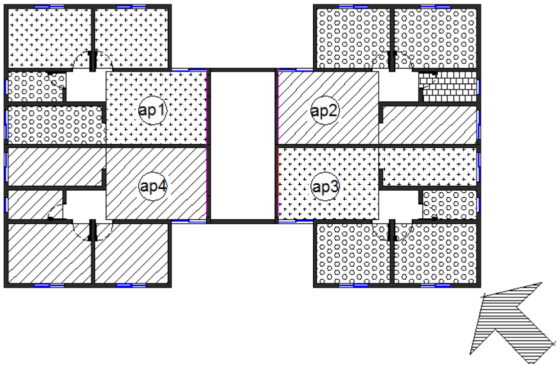

Figure 6: average speeds in case study 1- 135º wind

3.2. Case study 2

For winds at 0º (Figure 7), only the corner apartments 1 and 4 present regular ventilation. The other ones, whose openings are oriented to the same façade, and under the same wind pressure, do not present cross ventilation. This proves that, for efficient ventilation, it's important the pressure difference between the openings, otherwise there will be slight air movement, but not proper ventilation. The same can be observed at the 90º incidence (Figure 8), where only 2 of the 8 apartments present natural ventilation.

At 135º the situation the situation improves slightly (Figure 9) for the center windward apartments, because there's an increment of pressure difference between the openings, but this is not significant for thermal comfort. The best results are shown at the corner apartments 4 e 8, but in apartment 4 the ventilation direction is desirable (from the living room to the bedrooms and kitchen), while at apartment 8 it occurs in the opposite direction (ventilation coming from the kitchen to the living room), which is not desirable by the designer.

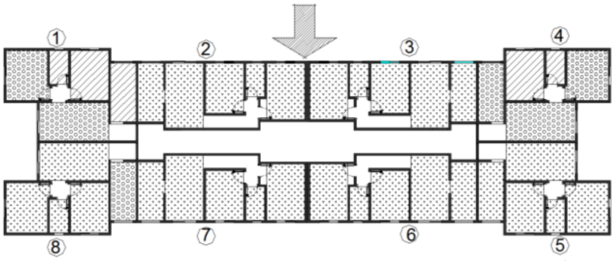

Figure 7: average speeds in case study 2- 0º wind

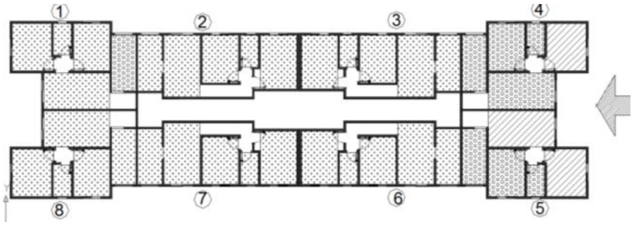

Figure 8: average speeds in case study 2- 90º wind

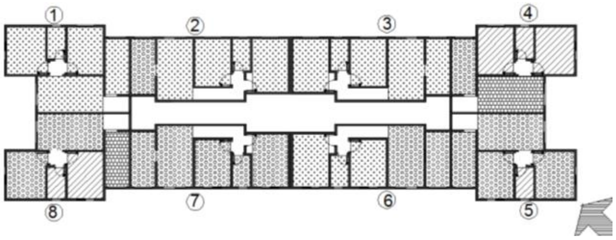

Figure 9: average speeds in case study 2- 135º wind

3.3. Case study 1 x case study 2

To compare the performance of the two typology it was performed statistical analysis of the database of average speeds for all rooms, the three analyzed floors and the three directions of prevailing wind. The analysis was performed using the R statistical software (version 12.2.0) [8]. The results are shown in Figure 10 to 13.

It can be seen from Figure 10 that, in case study 1, the rooms had the worst results regardless of the wind direction, contrary to what happened with kitchens and bathrooms. The fact that the two bedrooms are positioned side by side and especially with openings for the same façade causes a negative contribution to the internal ventilation of these rooms.

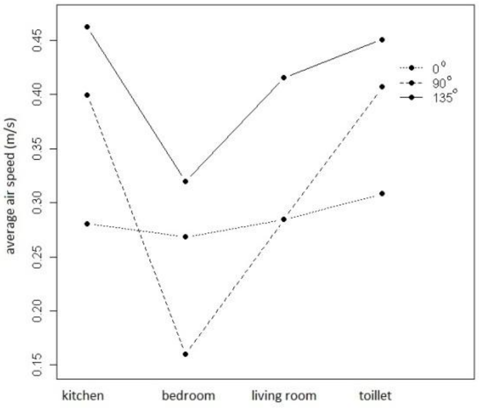

Figure 10: average velocities X room X wind direction Case study 1- Bassoli.

Figure 11 shows the performance of rooms for the case study 2, which fluctuates according to the incident wind. It should be noted that the performance of the corner apartments was higher than for the apartments in the center of the building, which virtually presented no ventilation in either direction. However it is noted in the graph, that the apartments located in the center of the building, which correspond to 50% of the apartments, have a large weight in the final average.

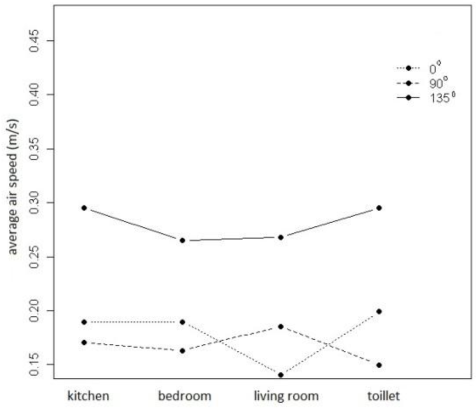

Figure 11: average velocities X room X wind direction Case study 2-Resaguas.

Figure 12 shows the performance of the two typologies in relation to the height of the floor. For Bassoli (case study 1) the averages found for the third and fifth floors are very similar and higher than for the first floor. For Resaguas (case study 2) the performance was worse and practically the same for all floors.

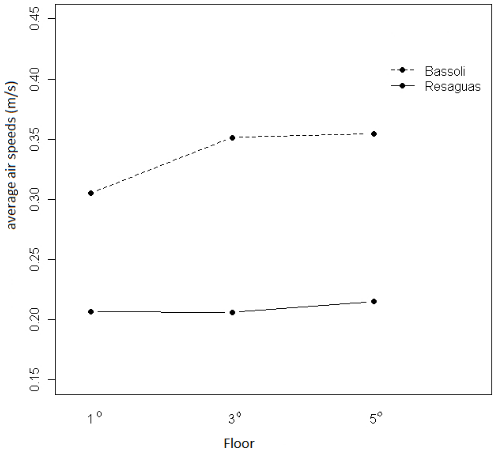

Figure 12: average velocities X height X typology.

Finally, when comparing the two typologies (Figure 12) with the incidence angle, it can be seen that the typology of case study 1 has a better performance than the case study 2 for all three different angles to the prevailing wind. The geometry of the building associated with the positioning of openings positively contributed to this result. Ventilation is inefficient for buildings with very long and monolithic facades (without indentations).

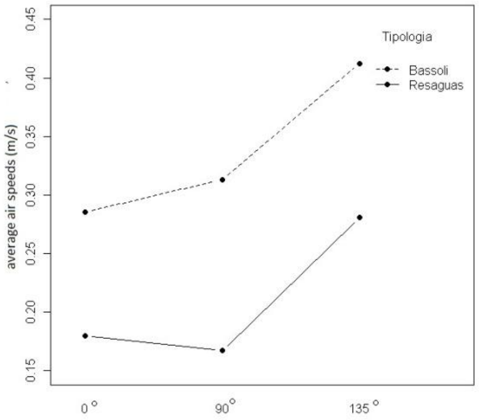

Figure 13: average velocities X wind direction X typology.

Regarding the positioning or the block orientation in relation to the prevailing wind, it must be emphasized the velocities for the wind at 135º (Figure 13), with the highest average speed. For winds at 0º and 90º it was not verifies statistically significant difference. In consequence, for the two typologies, it is indicated oblique implantation in relation to the prevailing wind.

4. CONCLUSIONS

In the two studied buildings, the formal symmetry compromises the housing units' efficiency. Therefore, the housing units' arrangement must be conceived and positioned according to the dominant wind direction, which was not observed, in these two examples.

The fact that the main entrance door remains closed, associated to the lack of ventilation in the common story hall, conditions the existence of cross ventilation only to the rooms with external openings. Therefore, the specification of ventilated internal door is a design resource that can improve the internal ventilation.

The floor height shows no significant influence on the results, on the contrary to what was expected, however, the geometry of the building together with the positioning of openings played a decisive role. The old theoretical discussion about form and function gains a new variable with the great impact of the geometry of the building on the natural ventilation of the apartments.

For neighboring bedrooms, we observed that the utilization of openings in different façades gives better results for the internal air flow than in bedrooms with openings oriented to the same façade.

The air flow direction should always be from dry to wet areas such as kitchens and bathrooms. Wet areas should be positioned as far as possible in the negative pressure zone or wind outlet, so that they will not contaminate other environments.

From the formal point of view, the building's reentrances are useful, since they help promoting pressure difference at the façades and benefits cross ventilation. Therefore, straight and monolithic façades must be avoided, specially the very elongated ones, since they promote only unilateral ventilation in the apartments.

In relation to building orientation, we noted that for the orthogonal wind incidences (0º, 90º, 270º and 180º), the number of apartments benefited by ventilation is lower than for the incidence of oblique winds. The 135º orientation and its variables (45º, 225º and 315º) showed to be better for the two studied typologies. Hence, positioning the blocks so that they receive the dominant wind diagonally is a simple way of improving the internal ventilation efficiency of the studied buildings.

It is worth noting that the factors previously described can be easily established still in the early design stage. Therefore, the utilization of computer simulation via CFD to predict natural ventilation proved to be efficient, and these recommendations can be used by designers still in early design process. Future studies are important, mainly to verify the influence of the surroundings in the blocks' internal ventilation.

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