

PHYSIOLOGICAL EQUIVALENT TEMPERATURE INDEX APPLIED TO WIND TUNNEL EROSION TECHNIQUE PICTURES FOR THE ASSESSMENT OF PEDESTRIAN THERMAL COMFORT

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Abstract

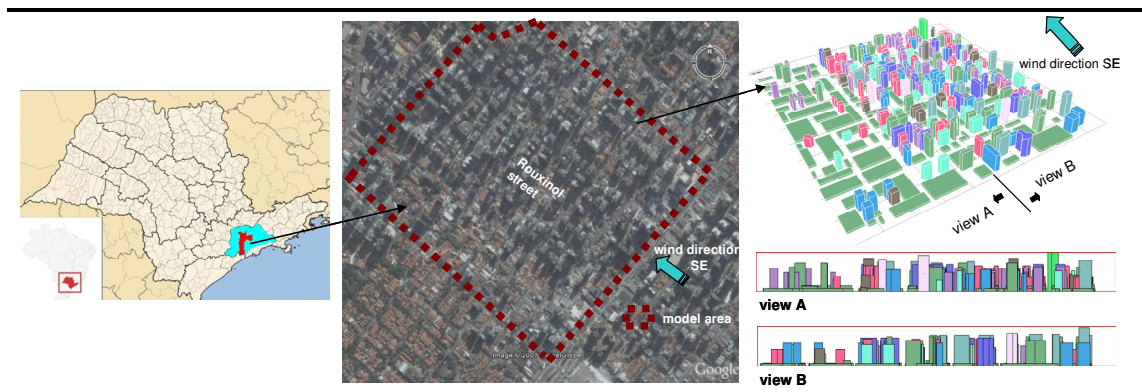
The goal of this research was to verify the influence of the effect of the wind on the pedestrians and the applicability of an index of environmental comfort for external spaces, according to data of wind tunnel simulations. The simulations were performed for the case study of Moema, an upper middle class verticalized residential neighbourhood in Sao Paulo, Brazil. The index used was the Physiological Equivalent Temperature (PET), established specifically for the evaluation of subtropical climates such as the one from the study area. Figures obtained from wind tunnel simulations, using erosion techniques, were used to visualize the field of speed in the level of pedestrian, describing the areas affected by the action of different wind speeds. The index was applied on the erosion technique pictures, defining the areas of greater and lesser influence in terms of the effect of wind on the climatic conditions of the site. As a result, one may verify the assessment of the area under study, observing the conditions of comfort and discomfort in light of changes in the values of wind speed.

Key words: thermal comfort indices, urban external spaces, wind tunnel simulation

1. INTRODUCTION

The metropolitan region of São Paulo has 20 million inhabitants, 11 million of which live within the capital's boundaries, making it the largest urban agglomeration of South America (Brandão, 2007). The city is crossed by the Tropic of Capricorn, located at the latitude of 23° 37' south and longitude of 46°39' west (FROTA & SCHIFFER, 1995). The study area is the district of Moema, located on the southeastern area of the city, one of the most affected by the verticalization and densification processes, with buildings ranging from 21 to 90 meters of height.

Figure 1: Brazil, Sao Paulo state and location the study area in Sao Paulo city



2. METHODS

2.1. Climatic data

While working with comfort in the built environment, a commonly found problem is the (un) availability of climatic data. Wind was chosen as the climatic variable for this study, since natural ventilation is the main strategy to attain comfort in São Paulo's climate.

Data for from a Test Reference Year (TRY), presented by Goulart et al (1997) was used for calculating the Physiological Equivalent Temperature (PET), which allowed for a visualization of the impact of wind distribution on pedestrian thermal comfort. Air temperature (t_a) was determined from the top and bottom 5% frequency of

occurrence from 6h to 18h. Three scenarios were established: a summer condition ($t_a=29,6^\circ\text{C}$), a winter condition ($t_a=14,9^\circ\text{C}$) and an average condition ($t_a= 22,3^\circ\text{C}$, the annual average temperature during the study period). In order to calculate relative humidity, absolute humidity from the period where $\Delta t_a= \pm 1$ was averaged, which resulted in three reference relative humidity values.

Mean radiant temperature was estimated from averaged solar radiation data for the periods where $\Delta t_a= \pm 1$. Solar radiation was calculated using a model from Kuwabara et al (2005), sky temperature by using the Bliss model (Duffie & Beckman, 1980), surface temperatures, according to IRC (2000) and surrounding temperatures from EDSL (2004). Whenever pedestrians were in shaded areas, mean radiant temperature was considered to be equal to air temperature. The calculations considered only wind data from the southeastern octant (azimuth = $135^\circ \pm 22,5^\circ$), with scalar wind speeds averaged for periods with $\Delta t_a= \pm 1$. Final scenarios for the three studied conditions were summer ($t_a^\circ\text{C}= 29,6$; $ur\%=42$; $trm^\circ\text{C}=56,8$ e $v\text{ m/s}=2,43$), average ($t_a^\circ\text{C}= 22,3$; $ur\%=70$; $trm^\circ\text{C}=37,4$ e $v\text{ m/s}=2,02$) e winter ($t_a^\circ\text{C}= 14,9$; $ur\%=92$; $trm^\circ\text{C}=25,9$ e $v\text{ m/s}=1,64$). Wind data was corrected according to BS5925 (1991), using $k = 0,21$ and $a =0,33$ (typical of city centers). Wind speeds for each isolines were corrected from the basic data present in item 2.3, resulting in eight values for each one of the three scenarios (Table 1).

Table 1: Scalar wind speeds in the isolines

isoline	velocity m/s (1,5m)			isoline	velocity m/s (1,5m)		
	summer	average	winter		summer	average	winter
1	0,58	0,48	0,39	5	0,35	0,29	0,24
2	0,52	0,43	0,35	6	0,33	0,27	0,22
3	0,47	0,39	0,31	7	0,30	0,25	0,21
4	0,39	0,32	0,26	8	0,28	0,24	0,19

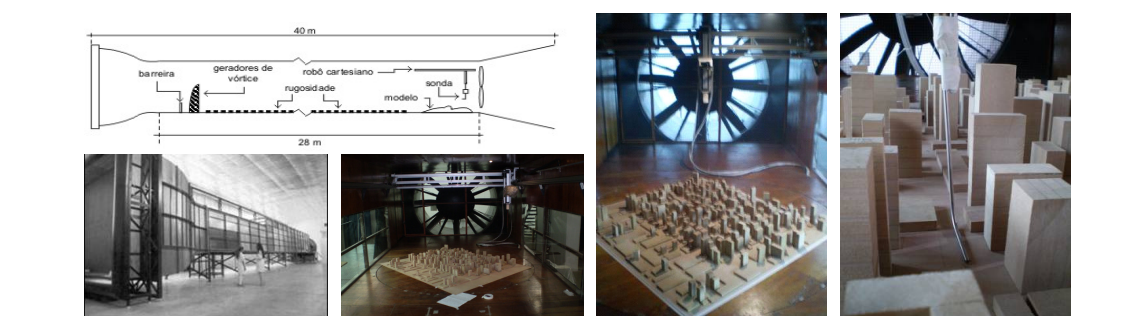
Finally, clothes insulation was considered to be $I_{cl} = 0,5$ in summer, $0,75$ in average conditions and $1,0$ in winter. Metabolical activity was considered to be $M = 135\text{ W/m}^2$.

2.2 Wind tunnel testing and physical model

This research used IPT's Atmospheric Boundary Layer Wind Tunnel (IPT - Instituto de Pesquisas Tecnológicas) (Figure 2). The tunnel works in a sub-sonic speed range (up to 30 m/s), low pressure and can generate two types of speed profiles. The test section is 3.00 m wide, 2.00 m tall and 28.00 m long, with a variable-height roof.

The model was built with 1:500 scaling, resulting in a 170x170cm area, representing a 600x600m actual area (Figure 2). Scale was determined so that blockage area would be inferior to 2% of the testing section of the wind tunnel. There was no need for adapting the model to the 2,60m of diameter circular board inside the tunnel. The study was carried on for the prevailing wind for São Paulo (Southeast-SE).

Figure 2: Physical model and the wind tunnel testing

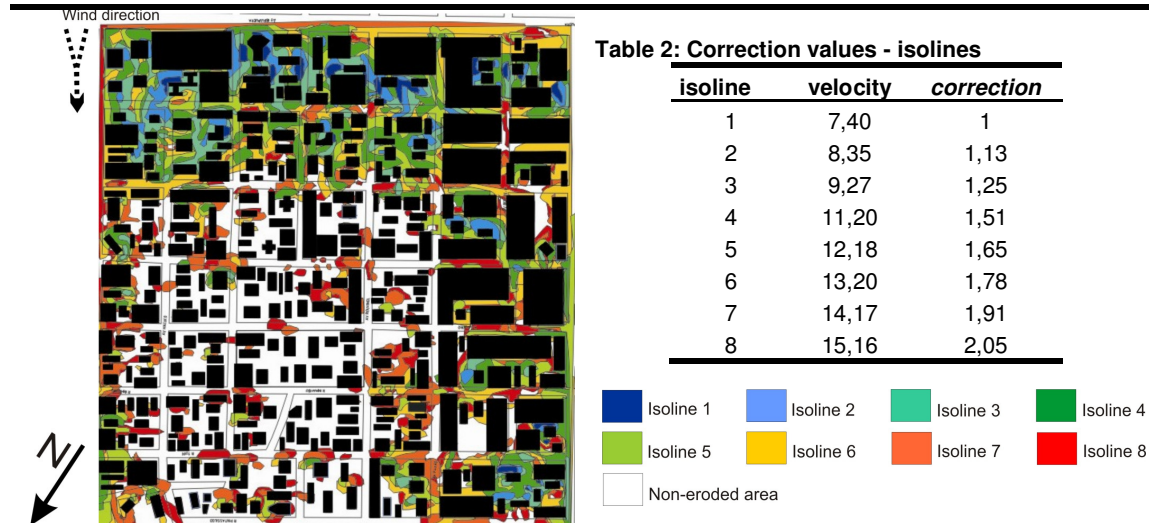


2.3 Erosion Figures Technique

The erosion figure technique allows for the visualization of the wind field at pedestrian level. It consists on spreading over the model floor (study area) a thin layer of sand. The air movement causes the sand to move and the erosion indicates wind speed above a given threshold around buildings (JANEIRO BORGES et al, 1979). By varying flow speed, one can obtain a group of lines/figures that correspond to the same boundary condition – friction velocity. Correction values below the unit indicate areas that are considered to be exposed, i.e. the sheer

stress over that surface is above the one verified in undisturbed flow. Correction values above the unit indicate sheltered areas where the erosive action of wind flow is reduced (Table 2). Figure 3 shows the wind field inside the study urban area, for a southeast incidence. Areas in white (not eroded) are areas with higher number of vertical buildings, which are also closer to each other. This area might present high turbulence problems, dust accumulation and/or areas where wind speed is not enough to remove the sand. Openings at pedestrian level throughout the group of buildings are indicated in order to increase air circulation around the area.

Figure 3: Results the erosion technique to study area – wind direction (Southeast-SE)



3. THERMAL COMFORT INDEX AND THERMAL STRESS – PHYSIOLOGICAL EQUIVALENT TEMPERATURE (PET)

Höppe (1999) proposes the Munich Model (MEMI), based on the human body thermal balance equation and on parameters from the two node model by Gagge (1986). Höppe's model differs from Gagge's model in the way of calculating regulatory sweat rate (as a function of t_{sk} – skin surface temperature and t_{cl} – clothed body external surface temperature) and the heat fluxes, for it considers clothed and unclothed body parts separately. By solving three equations (energy balance, heat flux from body core to skin surface and heat flux from skin surface to clothes external surface), one can determine the clothing external surface temperature (t_{cl}), the skin surface temperature and the core temperature (t_c). Höppe defines the PET for a given situation as the equivalent temperature to the air temperature in which, for a typical internal situation, the thermal balance of the human does not change, considering the same core and skin temperatures as in the original situation.

In order to calculate the PET, one should proceed accordingly to the following steps: (1) calculate the body's thermal conditions (t_{sk} and t_c), using the equation system from the MEMI model for the given combination of meteorological and individual parameter combination; (2) insert t_{sk} and t_c in the MEMI model, solving the system for air temperature (t_a), considering $mrt = t_a$, $w = 0,1$ m/s (proposed by the original model and recalculated for this paper, using wind speeds previously presented), $p_v = 12$ hPa, $M = 114$ W and $I_{clo} = 0,9$ clo; (3) the resultant air temperature is the PET. The PET index originally did not present reference ranges for interpretation, since it was developed to provide comparison with a reference environment. Monteiro & Alucci (2007) have proposed a calibration for the thermal sensation according to the following PET ranges: $> 43 =$ very hot; $31 - 43 =$ hot; $26 - 31 =$ warm; $18 - 26 =$ neutral; $12 - 18 =$ cool; $4 - 12 =$ cold e $< 4 =$ very cold.

4. RESULTS AND FINAL CONSIDERATION

The PET index is often used in environmental comfort researches for analyzing physiological behavior of users/pedestrians according to environmental conditions (effect of buildings and climate). Table 3 presents the results for the eroded areas from the wind tunnel tests, considering corrected wind speeds for the given urban configuration. The thermal sensation range is determined by the equivalent temperature, but it is important to consider on the final result the effect of local characteristics and of wind speeds. In this case, wind speed was the most significant variable for determining the PET thermal sensation range in the winter and summer situations,

while exposed to sun. In both cases, numerical values indicate proximity to neutrality, despite of the different variable inputs.

Table 3: Results of PET, in °C and calibration for the thermal sensation - Monteiro & Alucci (2007)

Colors - legend	isoline	summer		average		winter	
		Under the sun	In the shadow	Under the sun	In the shadow	Under the sun	In the shadow
MF	1	42,1	27,9	27,8	20,8	17,8	13,0
F	2	42,3	28,1	28,1	21,1	18,0	13,2
PF	3	42,6	28,2	28,4	21,2	18,2	13,4
N	4	43,1	28,3	28,6	21,4	18,6	13,5
PC	5	43,3	28,4	28,8	21,5	18,9	13,6
C	6	43,4	28,4	29,0	21,6	19,2	13,8
MC	7	43,6	28,5	29,4	21,8	19,4	14,0
	8	43,7	28,5	29,8	22,0	19,6	14,2

Legend: MF: very cold; F: cold; PF: cool; N: neutral; PC: warm; C: hot; MC: very hot.

Therefore, evaluation of pedestrian thermal conditions and integration of physical simulation with mathematical models may provide significant information for the definition of design strategies, which may assist the designer in defining use distribution and occupation directives for the area.

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