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An integrated approach for ventilation's assessment on outdoor thermal comfort

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A B S T R A C T

Modifications of urban structures that are linked to a lack of elements concerning climate interference in Urban Master Plans lead to environmental consequences that contribute to the thermal discomfort of pedestrians. Ventilation is especially relevant in promoting the necessary airing in regions with hot and humid climate, as is the case for the study site. This study aimed to evaluate the effect of ventilation on pedestrians' thermal comfort in coastal regions with hot and humid climates. This analysis was possible using an integrated approach to analyse urban layouts, thermal perception and urban legislation. An Integrated Method for the Analysis of Ventilation was thus proposed. The sampling area consisted of an urban stretch of Orla de Camburi, a seaside district in the city of Vitória, Espírito Santo (Brazil). The method used microclimatic measurements, which were recorded at the same time as questionnaires on thermal sensation were implemented. The field surveys occurred in winter, spring and summer, comprising six days of measurements and a total of 841 respondents. The survey results provide support for the proposal of a scale of wind perception and preference. The results also enabled the proposal of the calibration of the *PET* (Physiological Equivalent Temperature) thermal comfort prediction index to the climate reality of Vitória. Finally, the survey results promoted the creation of a system to evaluate the suitability of the Master Plan concerning issues about ventilation. The results reaffirmed the importance of using an integrated approach to evaluate ventilation considering pedestrians' thermal comfort.

1. Introduction

The urban environment expansion, associated with vertical growth and cities densification, affects urban climate and consequently population's thermal comfort. These changes on urban layouts affects climate variables magnitude and promote the formation of a mosaic of microclimates, which the urban climate is composed. Researchers in various places around the world have conducted urban climate studies. Cities growth and the conurbations they form has exerted a great effect on global climate and microclimate modifications, including natural ventilation [1]. Wind's change of direction and speed, associated to those of urban layouts, is a key element affecting cities climate [2].

Urban ventilation effectiveness depend of winds on several scales and of cities natural and artificial features [3,4]. To assure townspeople's thermal comfort, urban planning must intervene creating enhanced ventilation conditions. In tropical humid climate zones, ventilation is especially important to accelerate heat exchange between man and environment and thus promoting adequate airing. Urban sites arrangement of buildings affects the natural ventilation flow, so does vegetation. The vegetation's effect on airflow is more intense near the ground and depends on planting arrangement and species used [5–7].

One of the challenges to optimise natural ventilation is to define when it is desired or not [8]. Several studies have recognised this subject importance, and thus, several methods have been proposed whose results indicate that local climate features are crucial to establish comfortable ventilation limits. This fact implies global models evaluation inadequacy [8,9]. Cities growth associated with climate issues absence in urban planning instruments generates environmental consequences contributing to climate changes aggravation, especially with temperatures increase and heat islands formation. In addition to constitutional requirements, urban structures growth observed in Brazilian cities reaffirms local planning central role organising governmental actions aimed at collective welfare.

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From bioclimatology viewpoint, Hoppe [10] notes that microclimatic changes are one of urbanisation processes main consequences. Studies on thermal comfort in open spaces are more complex than those performed indoors because these studies involve greater oscillation in climatic conditions [11,12]. Although predictive indices attempt to balance climatic conditions and human thermal comfort, one must pay attention to each person's particularities. There is a wide application of the PET (*Physiological Equivalent Temperature*) index in thermal comfort studies, attributed in part to *RayMan*'s ease of use software [13] and also because uses a combination of climatic and personal variables as clothing and activity. PET's outcomes give a clear indication on the comfort temperature because it is still in degrees and therefore logical for people that are no experts in meteorology [14]. However, it is essential to note that this index is adapted to European reality and may not necessarily represent the real feeling of other areas users comfort. Several studies demonstrated this fact [12,15,16].

Researches as developed by Lin [16] shows that thermal adaptation, which involves physiological, psychological and behavioural factors, also plays an important role in assessment by users thermal environments. Study conducted in Taiwan, which has a hot and humid climate, examines outdoor thermal comfort and confirms thermal adaptation existence using PET index [16]. The formulae development to evaluate thermal comfort applicable to each local climate as well as multiplicity of thermal comfort predictive indices hinders both urban planning models application and studies results comparison. Thus, PET index was selected for its wide applicability in this research area [12].

To understand human thermal perception, more surveys in several contexts are necessary to understand regional particularities [17,18] and then to suggest some recommendations for improving urban planning by taking into account thermal comfort in tropical climates [18]. This study assumes as premises that urban layouts have an effect on local climatic conditions, that adequate ventilation for hot and humid climates is critical for mitigating thermal discomfort and that local planning is an important instrument to regulate urban structure. The ventilation aimed at pedestrian's thermal comfort covers different aspects, pointing to the need for a multidisciplinary approach to the matter. This study aimed to evaluate ventilation's effect on pedestrian's thermal comfort in hot and humid coastal regions through an integrated analytical approach of urban layouts, thermal perception and urban legislation.

2. Methodology

To achieve research's objective, an Integrated Method for Ventilation Analysis was developed. This method uses a multidisciplinary approach to evaluate urban ventilation, the study focus. Bearing in mind the adopted procedures, ventilation is analysed under three spheres: objective, subjective and legislative. The objective sphere is considered using urban typology analysis effect over the wind. In the subjective sphere, pedestrians' thermal comfort is analysed by wind's caused sensation. Finally, the legislative sphere considers how ventilation is addressed in the Urban Master Plan.

For the Integrated Method for Ventilation's Assessment, it was initially defined a sampling area in the city of Vitória, Espírito Santo's capital (Brazil), that presents different land occupation forms for wind behaviour pretended evaluation. In the sequence there are presented the main climate characteristics of Vitória, the measurement points identification and the urban legislation aspects that interfere in the analysis process.

2.1. Climate background

According to the Köppen-Geiger climate classification, Vitória's climate is humid tropical and is included in group A, i.e., hot and humid [19]. The tropical climate of low latitude regions, Vitória's case, features small temperature variations during the day. In addition, two seasons predominate, summer and winter, and the rainy season is not well defined with higher rainfall in the summer and a high relative humidity [20].

In Vitória, high temperatures are recorded in summer, and mild temperatures are recorded in winter. According to the National Institute of Meteorology (INMET) the city had an average summer temperature of approximately 27 °C while in winter was 22.8 °C, and in fall and spring were 24.3 °C and 24.7 °C, respectively [21]. Temperature has a 3.5 °C average daily range being highest temperatures recorded in noon period (10 h–16 h). Recorded average minimum temperature was 21.8 °C, and average maximum temperature was 29.1 °C, with an average relative humidity of 77%.

Wind speed is higher during spring and summer and lower during autumn and winter. In June, average wind speed was 3.11 m/s, year's lowest, while a value of 4.28 m/s was recorded in November, corresponding to the period (2000–2013) highest average speed.

2.2. Measurement protocol

Empirical analysis adopted method based on a climate sample covering eleven points arranged over two lines perpendicular to the waterfront. The goal was to cover different situations allowing a better understanding of urban typology effect on wind speed and direction (Fig. 1).

Measurement days criteria were defined by the ability to represent their season, therefore, were selected days with little cloudiness, with no rainfall and minimum wind speed of 5 m/s selected. These criteria aimed a better perception of wind and its changes by the instrument's sensor at a height of 110 cm, considering that the desired evaluation would be more evident during the type of days selected than on days with lower wind speeds.

Climate data collected at noon in winter and at 11 a.m. during spring and summer to ensure temporal similarity, keeping in mind daylight, savings time discrepancies. The afternoon period selected measurements for being thermal comfort issues most critical, because of highest daily temperatures. Time selection followed two criteria: amount of people on streets and solar path.

At selected time, which corresponded to lunch break, had the greatest number of people on streets observed. This was a very important factor concerning the increase in pedestrian's number for questionnaires application. The selected time was also the greatest solar height period, thus preventing buildings from forming shadows and from affecting visible sky area over sampling points, given that the buildings have different heights.

Microclimatic measurements from all eleven points performed using four portable mini weather stations located at each point. Stations were positioned at 110 cm from the ground (at abdomen height), following ISO 7726 [22] guidance, which rules measurements for physical quantities standards. Despite the variable wind be the focus of research, the mini-stations were used to obtain necessary data to calculate PET index. One digital portable hygro-thermo-anemometer, one datalogger, one globe thermometer, one windsock, one tripod and one weather shelter (Table 1) composed each mini weather station.

Thermal sensation data were obtained through questionnaire with pedestrians at each sampling points. The questionnaires aim