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Adaptive model for outdoor thermal comfort assessment in an Oasis city of arid climate

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ABSTRACT

One of the determining factors for the use of outdoor spaces is the experienced thermal comfort by people. There is a wide range of thermal indices. However, previous studies in Mendoza Metropolitan Area, Argentina, revealed that the predictive ability from six thermal comfort indices of international spread is less than 25%. This high contrast reveals the need for proposing an adaptive model to predict the thermal comfort conditions of the adapted population to this "oasis city" of arid climate. For this purpose, monitoring of microclimatic parameters and field surveys about the perception of the people on a pedestrian street were carried out in both winter and summer. Fourteen Multiple Linear Regressions were performed and the Akaike's information criterion was used to the model selection. As a result, a new model has been developed: the "Thermal comfort Index for cities of Arid Zones (IZA)". The formula considers air temperature, relative humidity and wind speed, all significant, independent each other and readily available variables. We found that the IZA's predictive ability is 73%, demonstrating the efficiency of the proposed model. Designers and urban planners may use the IZA as a simple and useful tool to improve the design of outdoor spaces.

1. Introduction

The study on outdoor comfort could be used to support design decision of outdoor public spaces. Extending the use of the spaces through a good design practice has the potential of increasing outdoor activity, leading to increases in commercial revenue, property values, and opportunities for social interactions. In addition, a good outdoor microclimatic condition could improve the indoor comfort level and thus reduce energy consumption [1–5].

The thermal quality of the outdoor environment varies significantly from the typical controlled interior thermal environment. Outdoor environment have greater fluctuations in temperature, humidity, air movement, radiant heat, solar radiation. Moreover, the complexity of the outdoor environment influences the variety of these parameters. Humans feel comfortable in a wider range of thermal conditions when inhabiting exterior environments because they feel that do not have control over the factors that determine the thermal qualities of the space [6–9].

It is recognized that the thermal comfort is not defined only by the environmental parameters. Human psychology also has a strong influence in the perception of comfort. Therefore, it is important to include psychological adaptation parameters, namely naturalness, expectations, experience (short/long-term), time of exposure, perceived control, and environmental stimulation in order to suitable prediction of outdoor thermal comfort [10–12].

In the context of this research, outdoor thermal conditions have been assessed through field surveys in the Mendoza city, Argentina [13–15]. People's thermal perception has been evaluated on a 5-point scale, varying from "very cold" to "very hot", and has been defined as the Actual Sensation Vote (ASV) by Nikolopoulou et al. [16,17]. The subjective data collected from the interviews was compared with six thermal comfort models of broad international spread: the Temperature-Humidity Index (THI), Vinje's Index (PE), the Thermal Sensation (TS), the Predicted Mean Vote (PMV), the energy balance *S* from COMFA model and the Physiological Equivalent Temperature (PET) [18–23]. These models were selected because they are widely used and have different levels of complexity. Although we are aware that some recently developed indices have not been considered, each of selected ones uses variables and approaches relevant to this field research. The six indices were calculated by taking into account the environmental parameters recorded

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for the duration of the interview, clothing levels and metabolic rate, for each interviewee. Results of this previous work revealed that there is a high contrast between subjective responses and the results produced by the different thermal comfort indices in both winter and summer. In fact, all models tested had very low percentages of predictive ability (under 25%). These results point to the need for a local model to properly assess the thermal comfort perceived by the inhabitants of the study city.

Therefore, this research focuses on the relationship between urban microclimatic variables and thermal perception. The hypothesis is that the prediction of thermal comfort in outdoor spaces requires a subjective approach for a given population adapted to certain climatic and cultural conditions. The goal is to propose an adaptive model or an empirical index to quantify the correlations between urban microclimatic variables and subjective variables (thermal perception). Although such empirical indices may be restricted to the geographical area or climate type, where the field survey was conducted, the advantage is its simplicity since does not require an iterative calculation. Likewise, the new model aims to predict the thermal comfort conditions of a population adapted to a given climatic condition, in this specific case, the Mendoza Metropolitan Area, Argentina, an oasis city in an arid area.

This new index is intended as a useful tool to assess the thermal behavior of outdoor spaces not only according to climatic criteria, but also to the subjective characteristics of users.

2. Study city

The research was conducted in the Mendoza Metropolitan Area (MMA) in central-western Argentina (32°40′S, 68°51′W, 750 m above sea level). It is the fifth largest city in the country with 1,055,679 inhabitants and 168 km^2 [24].

According to the Köppen-Greiger climate classification is an arid city: BWh or BWk depending on the isotherm used [25]. It is characterized by cold winters (average temperature in July: 7.3 °C) and hot summers (average temperature in January: 24.9 °C), with significant daily and seasonal thermal amplitudes. Winds are moderate and infrequent (average speed: 11 Km/h), the amount and intensity of solar radiation is high (percent of possible sunshine: 63%) and the average annual rainfall is 198 mm, with a concentration of 76% between October and March [26].

Currently it is estimated that approximately one third of the world population lives in extremely arid, arid or semi-arid regions [28]. Cities located in these areas display a compact urban model characterized by narrow streets and buildings with interlaced small-sized backyards. Created shades reduce the sun exposure in warmer seasons and, consequently, the heat accumulation on heavy material surfaces with high thermal admittance.

Although, MMA is located in a semi-arid region, it does not follow the aforementioned compact urban model. Their urban model is defined by its wide and tree-lined streets that form green tunnels (Fig. 1). The checkered frame contains the buildings while the main strategy for minimizing the sun exposure is the vegetal frame [29].

The forest matrix of Mendoza is accompanied by a system of irrigation canals formed by ditches [30]. The development of this matrix has allowed ‘green tunnels’ which give the feature of a real forest within the city. These qualities have been recognized locally and internationally and have earned the rating of the city as “oasis city” [31–33].

However, the intense forestation of urban canyons has been a decrease of available sky view factor (SVF) and increased roughness in the metropolitan area. Added to this, climatic characteristics (low frequency and intensity of winds and predominance of clear days) decrease the chances of passive cooling of the city by convection and radiation. Consequently the urban heat island reaches 10 °C, resulting in an increase of the needs of cooling [34]. The urban temperature increase has a direct effect on environmental pollution, energy consumption and thermal comfort — particularly in summer — [35–37]. Correa et al. [38] presents the geographical distribution of heating and cooling degree-days in Mendoza's Metropolitan Area taking into account the influence of urban heat island's intensity over the heating and cooling energy requirements in the city. The value of heating degree day (HDD) and cooling degree day (CDD) has been calculated from temperature data recorded at 16 fixed weather stations installed within MMA, measuring temperature and humidity in the urban canyons during a full yearly cycle. The calculation is performed using the Erbs's method and the interpolated data for the studied metropolitan area are mapped using GIS software. The results obtained have been compared with those data computations coming from nearest weather station, indicating that there is an under-estimation of CDD for the city downtown of approximately 20% respect to the value obtained from the nearest weather station, and in the case of HDD there is an over-estimation close to 50%.

3. Methodology

A broad and detailed description of the methodology used in this paper can be seen in Ruiz & Correa [39]. Nonetheless, here it will describe the following items: (a) the monitoring points, (b) the climatic data methodology, (c) the survey interviews methodology and (d) the statistical analysis and model development.

3.1. Monitoring points

The field study was developed in a central pedestrian street with large amounts of people. The place has shops, restaurants, shading

Fig. 1. Mendoza Metropolitan Area. Adapted from Martinez [27].