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URBAN THERMAL COMFORT: ANALYSIS OF THE IMPACT OF REVITALIZATION REVIVA CENTRO ON URBAN MICROCLIMATE OF CAMPO GRANDE

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Abstract: Green infrastructure is presented in several research as an urban strategy necessary to minimize the negative effects arising from the urbanization process and provide outdoor thermal comfort. The urban revitalization project "Reviva Centro", proposes the increase of vegetation along "14 de Julho" street, located in downtown Campo Grande, Mato Grosso do Sul, Brazil. In this sense, the aim of this study is to compare two scenarios, corresponding to the previous situations and after the implementation of the urban revitalization project. To compare the scenarios, the Envi-met program was used for 3D modeling and microclimatic simulation. The program simulates climatological interactions between surfaces, plants, and atmosphere, considering four fundamental variables of urban thermal comfort (temperature, relative humidity and wind speed and direction). The analysis and visualization of the results is based on the equivalent physiological temperature (PET), that classifies outdoor human thermal comfort conditions. Based on the results of the simulations, the increase in thermal comfort was provided in relation to cold and heat. At 8 am., an air temperature increases of 6 °C, decreasing the discomfort caused by the cold. At 16 hours the comfort gain is obtained by decreasing the air temperature, with a difference of 4.98 °C, optimizing thermal comfort in the scenario that represents the state after revitalization. The results presented in this research show the benefits of urban vegetation as a strategy to balance the urban microclimate and increase comfort for pedestrians.

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Keywords: Green Infrastructure; Thermal Comfort; Urban Revitalization; Envi-met; Physiological Equivalent Temperature (PET).

CONFORTO TÉRMICO URBANO: ANÁLISE DO IMPACTO DA REVITALIZAÇÃO REVIVA CENTRO NO MICROCLIMA URBANO EM CAMPO GRANDE

Resumo: A infraestrutura verde é apresentada em diversas pesquisas como uma estratégia urbana necessária para minimizar os efeitos negativos advindos do processo de urbanização e para proporcionar o conforto térmico urbano. O projeto de revitalização urbana "Reviva Centro", propõe o aumento da arborização ao longo da Rua 14 de julho, localizada no centro de Campo Grande, Mato Grosso do Sul, Brasil. Neste sentido, o objetivo desse estudo é comparar dois cenários, correspondentes às situações anterior e posterior a execução do projeto de revitalização urbana. Para comparar os cenários, recorreu-se ao programa Envi-met para modelagem 3D e simulação microclimática. O programa simula as interações climatológicas entre superfícies, plantas e atmosfera, considerando quatro variáveis fundamentais de conforto térmico urbano (temperatura, umidade relativa e velocidade e direção do vento). A análise e visualização dos resultados é feita com base na temperatura fisiológica equivalente (PET), que classifica o grau de estresse fisiológico humano ao ar livre. Com base nos resultados das simulações, um aumento do conforto térmico foi proporcionado em relação ao frio e ao calor. Às 8 horas da manhã, um aumento de temperatura do ar de 6°C, diminuindo o desconforto causado pelo frio. Às 16 horas o ganho de conforto é obtido pela diminuição da temperatura do ar, com uma diferença de 4,98°C, otimizando o conforto térmico no cenário que representa o estado posterior à revitalização. Os resultados apresentados nessa pesquisa evidenciam os benefícios da vegetação urbana como estratégia para equilibrar o microclima urbano e aumentar o conforto para os pedestres.

Palavras-chave: Infraestrutura verde; Conforto térmico; Revitalização urbana; Envi-met; Temperatura Fisiológica Equivalente (PET).

The urban thermal comfort is influenced by the relationship between the climatological variables and the urban environment characteristics. The climatological variables are temperature, relative humidity and velocity and direction of the wind. The urban environment characteristics are urban geometry, quantity of vegetation, water planes and surfaces materials (TSITOURA; MICHAILIDOU; TSOUTSOS, 2016; LAI *et al.*, 2019).

The green infrastructure is presented as a necessary strategy to minimize warming in cities caused by the urban heat islands (UHI) (OKE, 1987; KLEEREKOPER *et al.*, 2017; LIN *et al.*, 2017; POTCHTER *et al.*, 2018; ANTOSZEWSKI; ŚWIERK; KRZYŻANIAK, 2020; ELLIOTT; EON; BREADSELL, 2020). Through shading and evapotranspiration of the vegetation, it is possible to decrease the air temperature (DEMUZERE *et al.*, 2014) and increase the relative humidity, improving the human thermal comfort (LIU *et al.*, 2020), health (JAMEI *et al.*, 2016), well being and air quality

(CHAROENKIT; YIEMWATTANA, 2016; SANTAMOURIS; OSMOND, 2020). Thus, it is adherent to UN's Sustainable Development Goals, which are: SDG - 3 Good health and well-being; SDG - 11 Sustainable cities and communities and SDG - 13 Climate action, with incentives all over the world to promote urban green infrastructure (LIBERALESSO *et al.*, 2020).

The term green infrastructure is under study for more than two decades and it refers to ecological services that urban vegetation pays to the ecosystem in which it is inserted (BENTON-SHORT; KEELEY; ROWLAND, 2019), interconnected network of natural zones that maintain fresh air and ecological functions (BENEDICT; MCMAHON, 2006), such as vegetation, soil, bioengineering systems, for the improvement of the microclimate, air quality, habitat and better management of water (BOLUND; HUNHAMMAR, 1999).

Vegetation in the cities must respect the ecosystem involved, some native plants can be sensitive to urban modifications and pollution (MORAKINYO *et al.*, 2018), choosing low maintenance and not invasive species can be a more appropriate choice (TAN; JIM, 2017). Urban trees are an excellent tool for the microclimate improvement, tree planting on the streets must be studied so that their spacing does not obstruct the ventilation flow (YIN; LANG; XIAO, 2019). According to Erell (2017), the shading generated by the trees is more efficient when the treetops are bigger and with wide leaves, because this provides a bigger and more closed shading area. That is why the green infrastructure must be considered since its planning until maintenance needs (HUNTER *et al.*, 2019).

The temperature increases because of the capacity of a surface to liberate heat by convection and the afforestation reduces direct exposition to the sun and increases the air relative humidity, resulting in more comfort (ARAM *et al.*, 2019; CODER, 2011; LEE; JIM, 2019; MONTEIRO *et al.*, 2016).

To analyze thermal comfort at the individual's level, namely the physiological stress to maintain body temperature stable, it is necessary to understand the several indexes used to measure thermal comfort. PET (Physiological Equivalent Temperature) uses climatological variables, such as relative humidity, wind speed, temperature and solar radiation to result in thermal feeling. According to HOPPE (1999), PET is defined as the physiological temperature equivalent to the air temperature, the thermal balance of the human body to maintain central and skin temperature to the evaluated conditions. The use of urban vegetation impacts directly to the cooling of the urban environment, hence it influences the PET values in that analyzed environment (LUCCHESE, 2016; MORAKINYO *et al.*, 2019; WALTHER; GOESTCHEL, 2018).

For this investigation two scenarios were modeled: one of the state previous to the revitalization and other with the state posterior to the project's execution. The updated geographical data are taken under consideration so that it is possible to compare the results from the previous scenario to the scenario of the revitalization project.

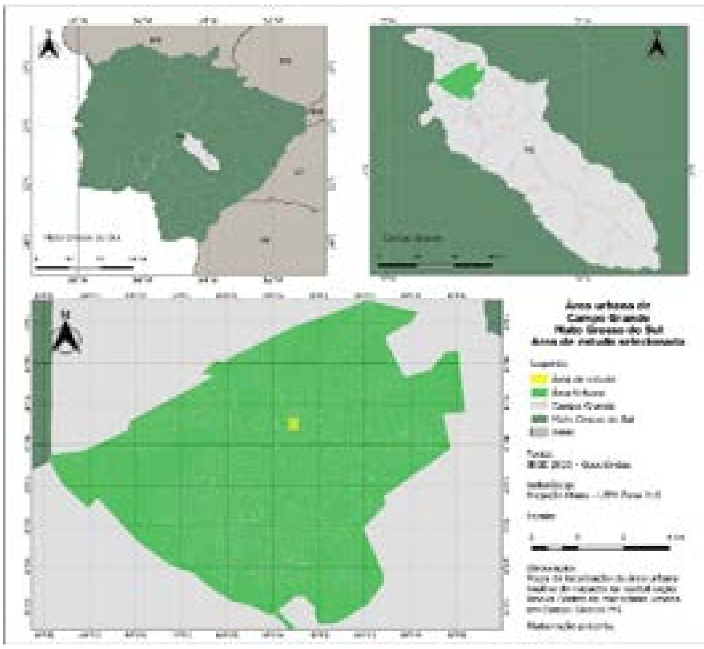
Material and methods

Study area

Campo Grande (20º28'13'' S, 54º37'25'' W, altitude of 600 m) is the capital of the state Mato Grosso do Sul, in the West Center region of Brazil. The estimated population for Campo Grande in

2021 is 916,001 inhabitants, according to IBGE (2021). The city has green spaces and important avenues afforested, for example Afonso Pena Avenue and Mato Grosso Avenue, both located in the central region. The part selected for the 3D modeling and computational simulation covers part of 14 of July Street, limiting to the intersections with Afonso Pena Avenue and Dom Aquino Street.

Picture 1 - Map of the study area location: Mato Grosso do Sul state, city of Campo Grande, urban perimeter of Campo Grande



Source: adapted from Souza (2017)

Computational simulations

In the analysis context of urban microclimate, one way to understand the relationship between the urban environment and the mechanisms of climatical regulation is the usage of computational simulation programs that decodify the urban nature.

These analysis studies of conditions to obtain urban thermal comfort can resort to methods of field measurement (REIS; LOPES, 2019)with positive effects on human thermal comfort. In this study, the cooling potential of all green spaces in Lisbon was estimated. For that, several mobile measurements of air temperature data were made in a single park (Gulbenkian's Garden, computational simulation (EVOLA *et al.*, 2017) or a combination of simulation and measurement to validate the results (TALEGHANI *et al.*, 2015).

Both scenarios are modeled using the *ENVI-met software*, with previous and posterior state to the revitalization project to compare results of air temperature, wind speed and air relative humidity; which are analyzed to obtain the gains related to the urban thermal comfort of each one of the respective scenarios.

Climate data

According to Souza, Paranhos Filho and Guaraldo (2020) the city of Campo Grande is placed in the transition zone between subtype Cf - Hot temperate climate completely humid and Aw -

Equatorial savannah with dry winter, according to Köppen's classification. The winter in Campo Grande starts on June 20 and ends on September 22, and it is considered the season with lower average values of annual temperature; average temperature data 1981-2010 (INMET, 2020).

The chosen season to evaluate the present study is winter, due to the gains that can be obtained in the balance of temperature range, in the cases the temperatures can be out of the range of thermal comfort feeling, in other words, uncomfortable in the heat as well as in the cold.

The computational simulation programs, in this case *Envi-met*, use as entry data for climatological variables, as air temperature, relative humidity (maximum and minimum), wind speed and direction. This group of information is called climatological file (FREDERICO *et al.*, 2020). For this study were considered data from hours measured for the period between 2008 and 2018 through data from INMET A702 Weather Station.

The meteorological data were extracted from the Hydro-Meteorological Information System (SIM) of INMET. These data were provided in *.xls* format archives, containing geographical coordinates, altitudes and climatological variables referring to the years from 2008 to 2018. The climate data resulting from the data treatment are presented in Table 1, are climatological variables from July, which represents the coldest month of the year in Campo Grande.

Table 1 - Climate data from 2008 to 2018

CLIMATE DATA JULY 2008 – 2018	
Wind speed in 10m high (m/s)	3,6
Wind direction (degrees)	67
Soil roughness	0,01
Air temperature, minimum (°C)	20,27
Air temperature, maximum (°C)	21,74
Air relative humidity, minimum (%)	55,13
Air relative humidity, maximum (%)	60,46

Source: Meteorological National Institute (INMET)

With the goal of evaluating the urban thermal comfort obtained with green infrastructure strategies presented in the project and executed in the urban revitalization, two scenarios were studied:

Scenario 1 almost does not present vegetation besides the central seedbed on Afonso Pena Avenue (main avenue of the city, it is famous for its seedbed with a lot of arboreal vegetation presence). 14 of July Street had a broader road, which implicated in narrower sidewalks, resulting in more presence of vehicles traffic.

Scenario 2 presents the result of the urban revitalization. As a consequence of the interventions, there was a reduction of the vehicles circulation and a substitution of the public road pavement, enlargement and substitution of the sidewalks pavement and an increase in the quantity of medium and big trees inserted along the extension of 14 of July Street (Picture 2).

Picture 2 - Photo of scenario 1 and photo of scenario 2

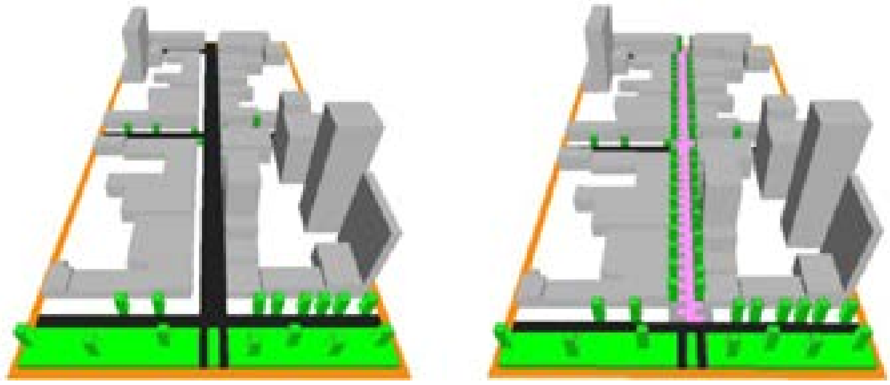
Source: Google Maps (2018) and photo from the author's archive (2021).

These scenarios were modeled in three dimensions with the tool *Spaces*, from ENVI-met program:

Scenario 1: Situation of 14 of July Street before the revitalization, broad street with three lanes and parking on the sides, narrow sidewalks and no trees (Picture 3).

Scenario 2: Current situation, after the execution of the revitalization project of 14 of July Street, narrowing and substitution of the street pavement, broadening and substitution of the sidewalks pavement (Picture 3).

Picture 3 - Scenario 1 (situation previous to the urban revitalization) and Scenario 2 (situation posterior to the urban revitalization) modeled with Spaces tool from ENVI-met 4.4.3



Microclimate simulation

In order to analyze the impact of the urban revitalization through a computational simulation, the software *Envi-met* 4.4.5 was used, according to the fundamental laws of fluid dynamics and thermodynamics (BRUSE; FLEER, 1998), considered an important tool for microclimate analysis of urban areas (TSOKA *et al.*, 2020).

After the analysis and extraction of the necessary data, the area modeling was elaborated on the *Spaces* tab. The vegetation and surface materials were adapted to the *ENVI-met* 4.4.3 software database and their nomenclatures were aligned, according to the model of Silva *et al.* (2019).

To determine the size of the trees, we collected information at the Landscape Project Memorial (FERNANDES, 2015). The arboreal species described at the memorial have between 8 and 12 meters high, for the simulation a 10m high tree was used from the program's data bank. For the setting of the climatological file, the *ENVI-guide* function was used, the period chosen for the simulation was the month of July, considered the coldest of the year in Campo Grande (IBGE, 1981-2010). The data requested to run the simulations are the same presented on Table 1.

The simulations were calculated for a day in July of 2020, in a period of 48h, starting at 7 o'clock in the morning, close to the sunrise at this time of the year. According to the program's recommendations, it is necessary to calculate 48 hours in order to be able to extract the results referring to the second day of simulation (BRUSE, 2004).

To view the results of the variables of air temperature, wind speed, air relative humidity and PET, the data were extracted in the *Leonardo* tool of the *ENVI-met* 4.4.3 program. The atmospheric data generated by the computational simulation were inserted and the parameter analyzed from the choice of time defined to compare one scenario to the other.

Results and Discussion

Analyzing the results of air temperature for 8 am., the difference between the minimum temperatures presented is 5.7 °C. Scenario 1 presents the situation of minimum temperature (14.46 °C)showing more heat loss during the night (Table 2). In scenario 2, the presence of the vegetation causes a balance between gains and losses of heat, thus decreasing the daily temperature range.

The minimum air relative humidity happens in scenario 1 (53.03 °C) at 4 pm. (Table 2). In every time analyzed, the RH presents higher values in scenario 2, this is due to the evapotranspiration effect of the vegetation. It is worth to emphasize that in scenario 2 the region under analysis is closer to the salubrity situation indicated by the World Health Organization (WHO) for RH percentage, which is at least of 60%.

In order to evaluate the gain of thermal comfort it is necessary to take under consideration the values presented in the physiological equivalent temperature (PET) index, that establishes as comfortable, in other word, without physiological stress, values between 18 and 23 °C. As aforementioned, the green infrastructure inserted in the urban context of 14 of July Street, through the execution of REVIVA project, helps in the urban thermal comfort.

Table 2 - Results of the simulations for scenarios 1 and 2 in different times of the day

Scenarios	Times	Air temperature (°C)		Relative humidity (%)		Wind speed (m/s)		PET* (°C)	
	(24h)	min.	max.	min.	max.	min.	max.	min.	max.
1	8am.	14,46	21,13	40,26	66,43	0,00	13,29	8,00	37,00
2	8am.	20,16	21,27	57,24	63,34	0,00	12,56	15,00	40,00
1	1pm.	19,59	23,40	41,26	56,92	0,00	14,49	18,00	54,00
2	1pm.	19,98	23,75	51,54	59,01	0,00	12,98	17,00	55,00
1	4pm.	19,54	27,80	40,80	53,03	0,00	14,78	21,00	43,00
2	4pm.	20,05	22,82	53,53	58,26	0,00	13,54	15,00	41,00

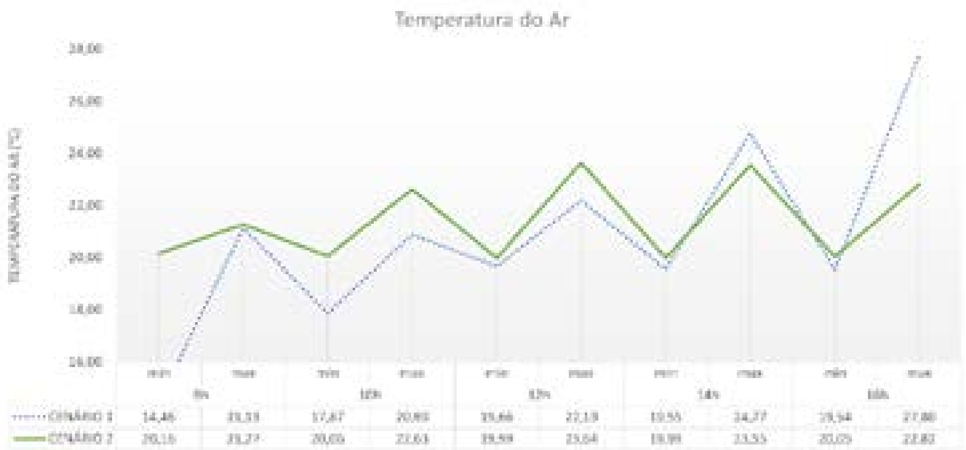
By seeing the values presented at PET, scenario 1 presents minimum PET of 8 °C, while scenario 2, 15 °C; this means an increase of 7 °C, in terms of physiological stress degree, this difference soothes the stress caused by the cold. The second time that reflects the gain of thermal comfort obtained with the increase of the urban vegetation, was at 4pm., period when the accumulation of heat caused by the solar radiation results in the maximum value of temperature of the day. In this case the thermal comfort is reached by the decreasing of the maximum temperature. At 4pm. in the the scenario previous to the revitalization, the maximum temperature is of 27.80 °C, and in the scenario post revitalization this value gets to 22.82 °C, a difference of 4.98 °C (Table 2).

Comparing the results of graphic 4, we verify that a lower temperature range is observed for line if Scenario 2. With respect to the maximum temperatures between the two scenarios, the biggest difference happened at 4pm., which were approximately of 5 °C in the maximum temperature (Picture 4).

Considering that the month analyzed is in winter, it is also important to highlight the data of the minimum temperature presented at 8am., they went from 16.16 °C to 20.11 °C, which means that the benefit generated by the urban vegetation mitigated the thermal discomfort caused by the cold as well as the heat.

This contrast is due to the shading and evapotranspiration effects provided by the urban vegetation and, consequently, reflects directly on the minimum and maximum relative humidity results (Picture 5).

Picture 4 - Chart of air temperature on scenarios 1 and 2



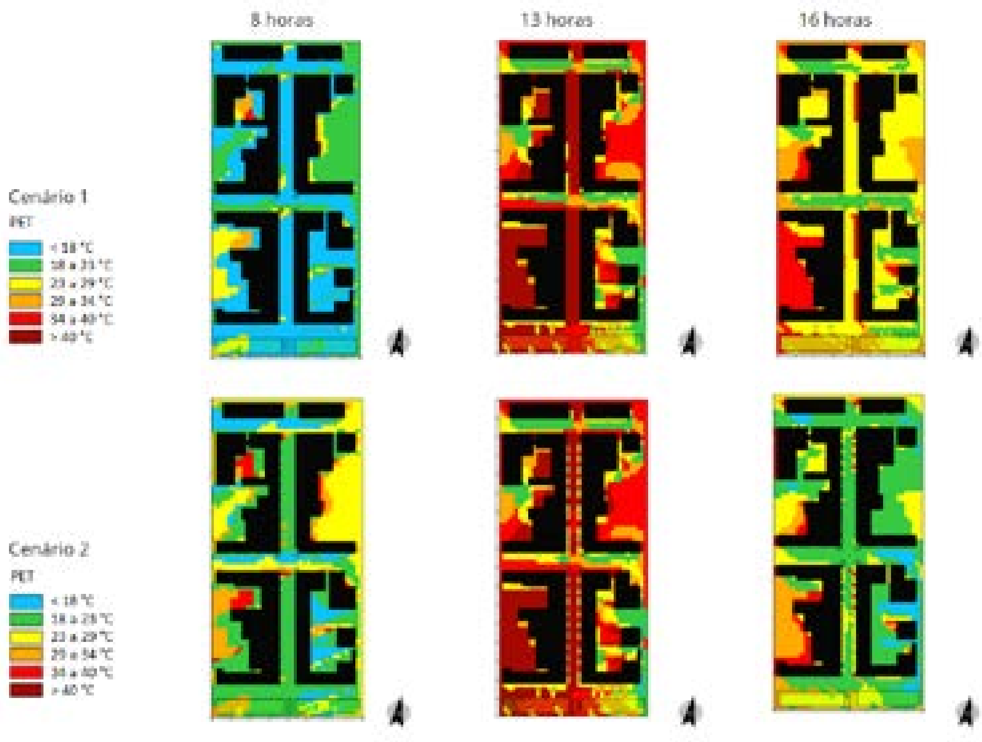
Picture 5 - Chart of air relative humidity on scenarios 1 and 2

With the increase of arboreal vegetation inserted along 14 of July Street, the balance scenario 2 presents in relation to the relative humidity values of scenario 1 is quite evident. The evapotranspiration effect allows to balance the air relative humidity values, the maximums and minimums come to a minor range.

With respect to all the times presented on Picture 5, the analysis of the air relative humidity indicated the increase of the minimums and maximums as of 12 o'clock, in scenario 2 (Picture 5). With the tool *ENVI-met BIOMET*, the program processes data resulting from the simulations and calculates the human thermal comfort index, in the study case in analysis, PET was chosen, which is organized in nine classes, with values between 18 °C and 23 °C, considering the human thermal comfort feeling.

The following maps showing 14 of July Street between Afonso Pena Avenue and Barão do Rio Branco Street highlight the differences between the two scenarios (Picture 6). The most even energy balance is visible with the minor temperature ranges and thermal neutrality feeling for most of the time in scenario 2. The road axis remains in thermal comfort situation in two of the times analyzed (8am. and 4pm.) and presents an improvement in comparison to scenario 1 at 1pm.

Picture 6 - PET results at the following times: 8am., 1pm. and 4pm.



Final considerations

With the *ENVI-met* 4.4.3 program a study was performed to quantify the thermal comfort optimization generated by the urban revitalization project "Reviva Centro" on 14 of July Street. The results present improvements in the parameters air temperature, wind speed, air relative humidity and human thermal comfort feeling, confirming that the green infrastructure is an efficient tool for the urban comfort improvement in micro-scale and that, being a part of the ecological structure, it contributes for the mitigation of urban heat islands.

The intervention with the increase of the urban vegetation for the winter scenario enhances the comfort at 8a.m. The PET thermal perception in scenario 1 is classified as mildly cold, but in scenario 2 the results show an improvement along the street evaluated and a green spot is noticed representing a comfortable thermal perception. At 1pm, when there is more exposition of the surfaces to solar radiation, trees promote a slight difference of comfort along the street, due to the shading that is projected where there is more circulation and permanence of people. The PET results for 4pm. indicate the increase of the thermal comfort. At this time the air temperature tends to be more elevated due to the increase of temperature of the urban surfaces. The difference between scenarios 1 and 2 is evident at the PET classification that goes from mildly hot, hot and very hot to an growth of the comfortable area.

The software allows an evaluation of the impact of the vegetation in hypothetical scenarios that simulate a real urban sample, this type of technology allows to observe the alterations of the climatological variables from one scenario to another and to understand how the wind and heat fluxes relate in an environment with and without vegetation. Modeling and simulating several scenarios can help urban planners in the choice of species and different spatial distributions on the planting of trees in the urban context, considering the local climate of each city.

It is also possible to highlight that the benefits obtained with the modification of the built environment go beyond the promotion of the thermal neutrality feeling, extending to the promotion of biodiversity, water management and improvement of the air quality.

Being able to use a part of the city as an experiment laboratory allows us to create models and test them through computational simulations that determine the success of the implementation of urban an environmental intervention projects in urban perimeters.

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