Using Computer Simulations for Assessing Microclimatic Impacts of Urban Interventions

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ABSTRACT: The purpose of the present paper to estimate the impact of alterations in urban design on local microclimate in three different locations: a densified area of São Paulo, Brazil, a district in Paris, France and an industrial area in Geneva, Switzerland, which is undergoing urban redevelopment. Computer simulations were run with the program ENVI-met in all cases, including a calibration procedure from in situ measurements. The effects of the introduction of urban parks and greenery are assessed in terms of local temperature reductions, under summer conditions. It was found that by introducing vegetation in the urban environment, temperature reductions can range in those cities between 0.6 and 2.2°C and in some cases the effect is highly localized, pointing to the importance of better greenery distribution in cities rather than concentrated urban parks.
Keywords: ENVI-met, microclimatic impact, vegetation

INTRODUCTION

The heat waves can be responsible to a rise in mortality rates in temperate regions, due to dehydration and hyperthermia, affecting in particular the elderly. Urban design strategies are known to be capable to mitigate those effects in view of global warming trends. The use of vegetation can create positive effects in terms of cooling, which can be local and to a certain extent be responsible for changes in the thermal field of whole areas (street canyons, urban parks, etc). According to Olgyay [1] solar radiation can be lowered as much as 60-90% leading to ambient temperature reductions and lower surface temperatures. Mascaró [2] suggest that under a group of trees ambient temperature reductions can reach 3-4°C when compared to more exposed areas.

Urban planning can benefit from the use of computational tools for predicting possible consequences of future urban scenarios therefore aiding decision making. In this paper, we analyze by means of the CFD-based software ENVI-met the impact of greenery introduction on urban climate in summer at three locations (São Paulo, Geneva and Paris).

METHODS

ENVI-met is a microclimate simulation tool designed to evaluate plant-surface-air interactions at 0.5 to 10m spatial scale and 10s temporal scale. It is under continuous development by Bruse et al. According to Bruse [3], the model is capable of handling aspects of the flow around and between buildings, turbulence and particle and substance dispersion. As examples of applications, Ali-Toudert [4] has thoroughly reviewed the mathematical model behind ENVI-met in his simulations of urban canyons in hot and dry climates; Spangenberg et al. [5] have analysed the influence of vegetation in thermal comfort in the city of São Paulo, by means of weather data measurements and simulations. The version used in the present study is ENVI-met 3.1 Beta 5. For displaying results as thermal maps, the extension Leonardo 3 ENVI-met was used. Basically, two files are required for the simulation of the urban environment: the 3D model of the area of interest and the initial configuration data.

CASE-STUDY IN SÃO PAULO BRAZIL

The purpose of this case-study was to recommend urban design solutions for improving the thermal environment in a given area of the city of São Paulo (23°37'S), which shows thermal inadequacy as verified in a thermal Landsat image of São Paulo [6]. The Belém district is densified and sparsely vegetated. Microclimate data were obtained by field measurements during daytime at a N-S street with a Sky View Factor (SVF) of 0.6, in February 2011, totaling 13 hours of daytime measurements, carried out in two days. For that, a HOBO weather station was employed (model H21-001), equipped with temperature and humidity sensors (S-THB-M002); silicon pyranometer (S-LIB-M003); three cup anemometer (S-WCA-M003); and copper gray-coloured globe thermometers (type PT-100). Measurements heights were 1.1m (Ta, RH and Tg), 1.5m (Ig) and 2.1m (v).

Modelling approach and calibration

The perimeter of the Belém area (Fig. 1) in the model is 366m (x-axis) by 390m (y-axis) with a grid resolution of 6m. A digital map of the area as well as Google images was used for the 3D modeling. A receptor (P1) was inserted in the model at the approximate location of the monitoring point for the purpose of model calibration. Trees are represented as dark grey squares along the street canyons.

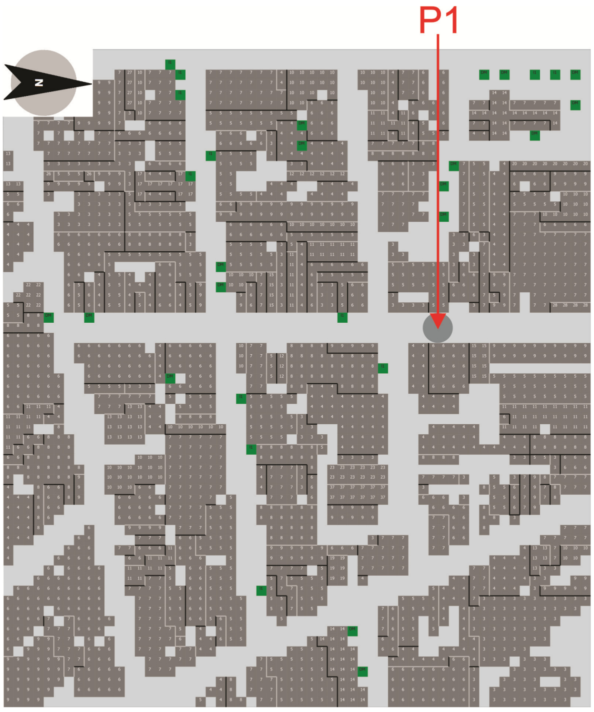


Figure 1: São Paulo: Belém model

Several days were run using mean data registered at the Mirante de Santana meteorological station (located in the northern part of the city) until a convergence was found between measured and simulated air temperature data. Mean error was found to be less than 1ºC for p>0.05.

Simulation scenarios for Belém

The thermal effect of adding trees (15m high, LAD 0.000 0.000 2.180 2.180 2.180 2.180 2.180 2.180 1.720 0.000) was evaluated, for two scenarios:

- Scenario 1: adding a row of trees on one side of the evaluated street (the East-facing façade of the N-S street), thereby raising the almost bare street to a vegetated fraction to 22%;
- Scenario 2: adding rows of trees on both sides, creating a "green corridor" and doubling the vegetated fraction to 44%.

Results

Results are shown for 3pm, when temperature reductions were more significant (Fig. 2). Mean air temperature reduction on the one-sided vegetated street was 0.8°C and at the green corridor 1.2ºC. At the monitored point, temperature reductions were somewhat greater: 1.0ºC for scenario 1 and 1.8°C for scenario 2.

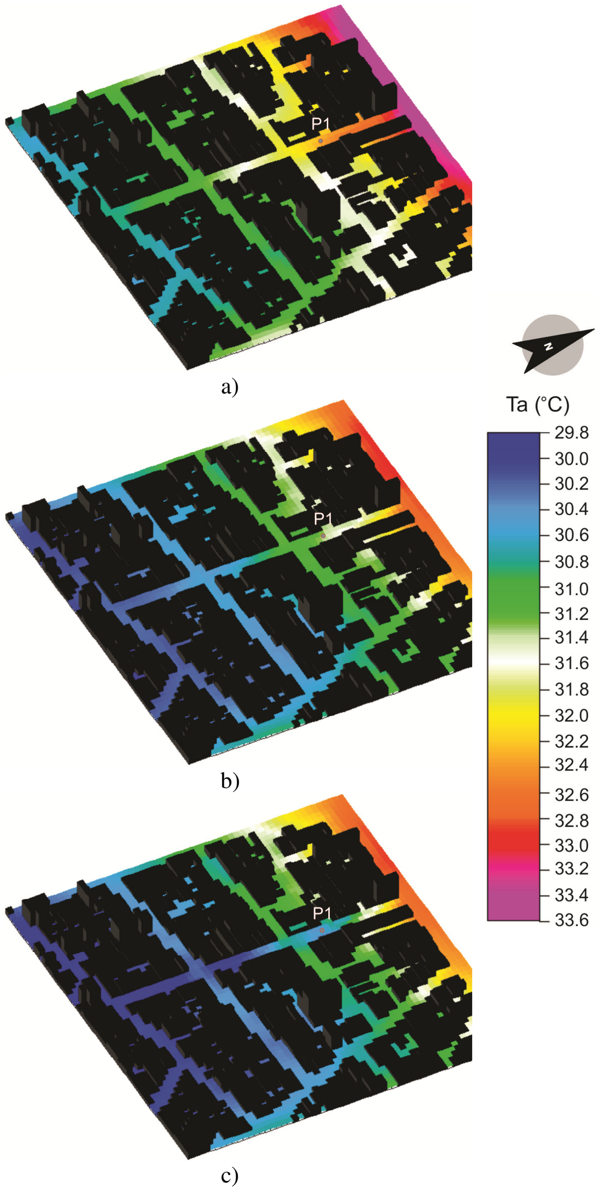


Figure 2: São Paulo: thermal images from ENVI-met for a) the original conditions, b) scenario 1, c) scenario 2

CASE-STUDY IN PARIS, FRANCE

The possible impacts on local microclimate of three proposals for improving urban areas in the surrounds of 'Gare de l'Est' railway station in Paris (48°24'N) are analyzed: the suggestion of the team led by the architect Richard Rogers, part of the 'Grand Paris' set proposal [7] which combines transport, urban mobility and green areas; the 'ZAC Pajol' [8] proposal, a major eco-neighbourhood with the introduction of 1ha of green areas; and the 'Jardins d'Eole', which consists of an urban park with 4ha.

Daytime microclimate measurements were carried out on three consecutive days in August 2011 at two different locations around Gare de l'Est (P1 and P2, Fig. 3), which had a similar SVF of approximately 0.6. P1 was on a bridge above railway tracks and P2 on a street next to the train station.

Two weather stations were employed, both equipped with the following instruments: temperature and humidity sensors (HC2S3 Rotronic), globe thermometer (type PT-100) and pyranometer (SP Lite2 Kipp&Zonen), all at a standard height of 1.30 m. The anemometer (Windsonic Gill Instruments) was positioned at 1.90 m above ground. Campbell loggers (CR10X) were set to record data in 10s intervals; data were then averaged for the minute.

Figure 3: Monitoring points in Paris: a) P1, b) P2

Modeling approach and calibration

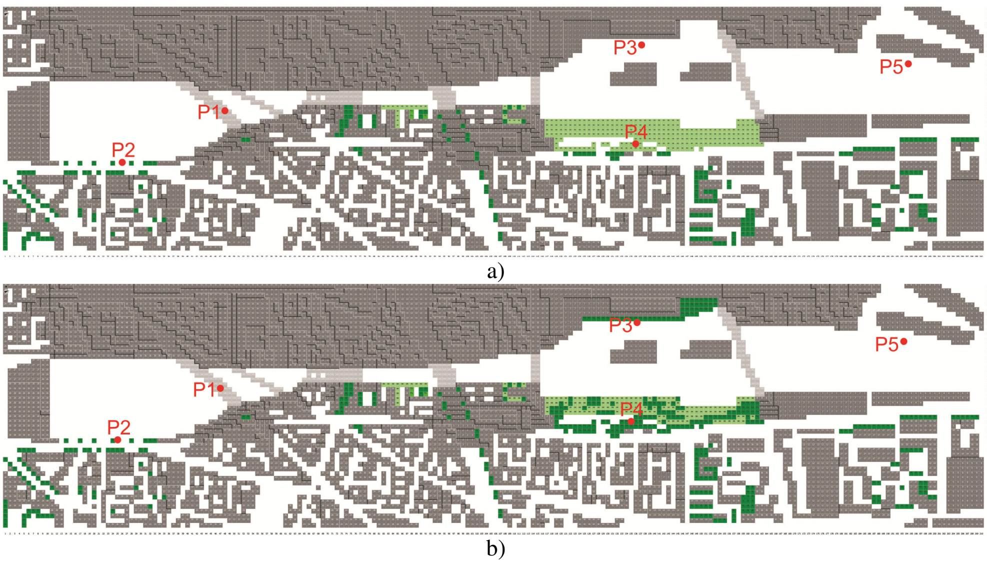
Comparisons were drawn for the two points between measured and simulated data and for the third day of measurements. It was noticed that due to the empty spaces (urban voids) a convergence of measured and simulated air temperature curves (for the monitored period of 5 hours) was found for the very first day run, thus the first simulated day was used for testing the different scenarios. Reference data used as input for ENVI-met were taken from the Meteorological Observatory of Montsouris. Starting wind and air temperature data had to be slightly modified in the process of model calibration. Mean error was low and virtually zero (with $p>0.05$ for P1 and P2). The model comprises an area of approximately 2.1km (x-axis) by 0.5km (y-axis), considerably larger than Belém's (São Paulo). Grid size used was 10m. A limitation of the model was due to a varying topography in the region analysed, which could not be modelled in ENVI-met.

Simulation scenarios

Two hypothetical scenarios were tested: scenario 1, comprising the arborization plan of 'Jardins d'Eole' (P4) and the interventions proposed in the 'ZAC Pajol' (P3) project; scenario 2, with green areas being added to the first scenario, as in the 'Grand Paris' proposal. In both scenarios, the added trees are of dense canopy, as in Belém/São Paulo. Changes in greenery percentage from the initial conditions were of about 3% in scenario 1 and of 17% in scenario 2. Figure 4 shows the original scenario and the two scenarios tested.

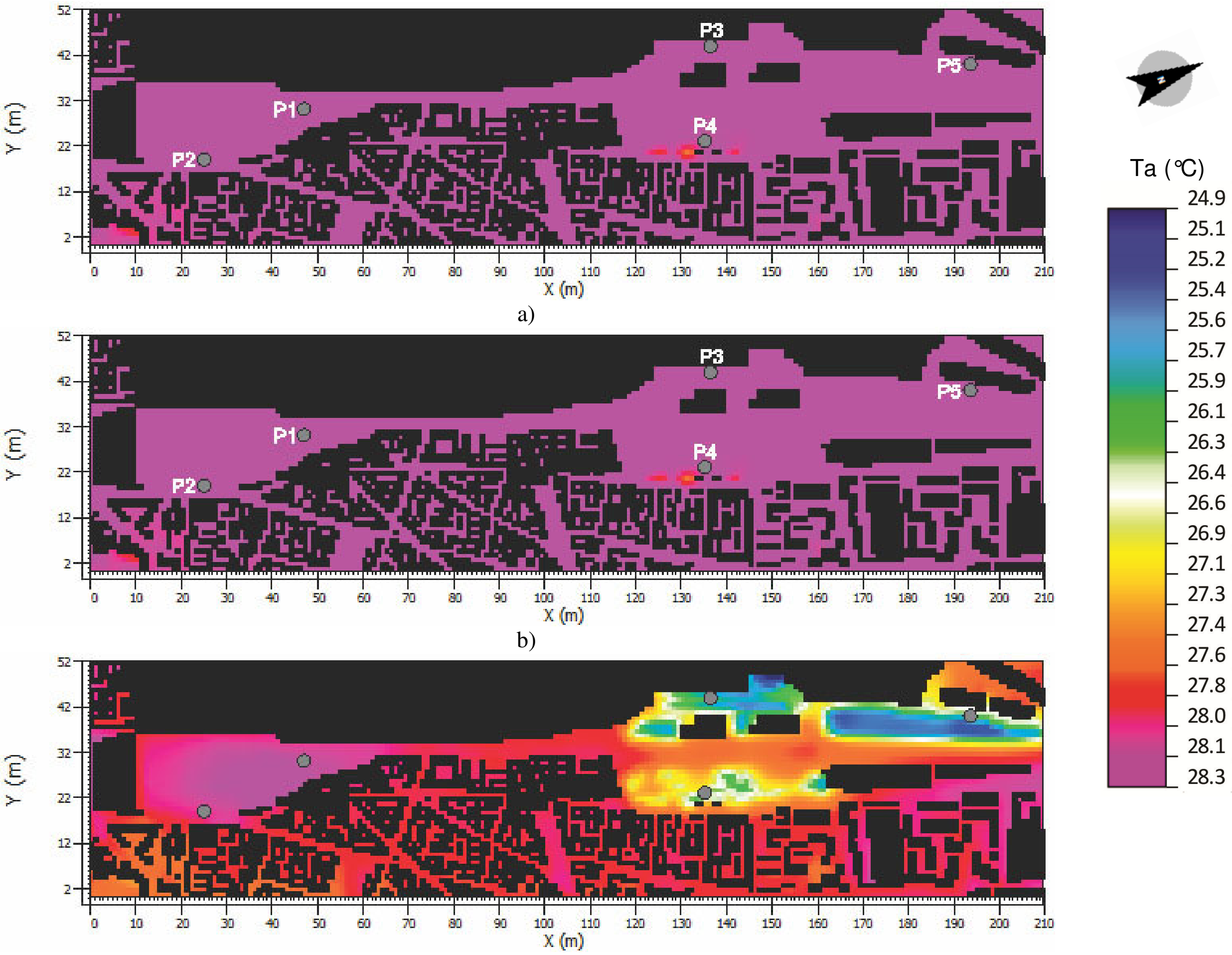
Results

An evaluation of the overall reduction in air temperature of the modelled area (Fig. 5), disregarding the elevated area, yielded for scenarios 1 and 2 a 0.2°C and a 0.6°C drop from the original situation, respectively. Localized effects on particular points across the modelled area, however, showed air temperature reductions as high as 1.7°C for scenario 1 (P4 at 7pm) and of 2.4°C for scenario 2 (P3 at 7pm).



c)

Figure 4: Paris: a) original scenario, b) scenario 1 and c) scenario 2



a)

b)

c)

Figure 5: Paris: thermal images from ENVI-met for a) original scenario, b) scenario 1 and c) scenario 2

CASE-STUDY IN GENEVA, SWITZERLAND

As a measure of tackling the problems of urban decay, excess commuting and urban voids in Geneva (46°12'N), and with the aim of establishing an organized urban development, projects like the Praille-Acacias-Vernets (PAV) have been conceived. The urban development proposal for the surrounding area of the Praille Railway Station termed Société simple de valorisation de terrains à Genève – La Praille (SOVALP) is evaluated in regard of microclimatic aspects. The project intends to improve natural and social components in the built environment. Public spaces will link buildings to public and private transportation, while squares and parks are introduced. Microclimate measurements were carried out at two points (P1 and P6, which are located close to the railway station and next to the railway tracks, respectively) in August 2011 during daytime, with the same instruments and according to the same procedure used for the Paris monitoring campaigns.

Figure 6: Location of the two monitoring points (Google Earth image and authors' archives)

Modeling approach and calibration

Modeling of the study area was based on site plans and building heights data provided by the City of Geneva and on Google Earth satellite images. For modeling future scenarios, building heights, plans and vegetation were added based on the illustrative images of the SOVALP Project. The modelled area corresponds to approximately 380m × 230m with a grid size resolution of 5m. With regard to vegetation, grassy areas with 20cm height were inserted and the existing trees were considered as "tree, light 15m". As in Paris, possibly due to the existence of urban voids simulation results matched measured data on the first simulation run (first day). Reference meteorological station located at Geneva's International Airport provided input data for analysis; input temperature and wind speed data were very close to measured data during model calibration. Mean error was rather low (<0.2°C).

Simulation scenarios

Three scenarios were evaluated in ENVI-met: scenario 1, as in the SOVALP proposal [9]; scenario 2, with the addition of grassy areas to scenario 1; scenario 3, with the insertion of dense 15m tall trees and changes in the spatial distribution of trees.

Adopting scenario 1 as a reference for comparisons, since in this first scenario changes in morphology are also present along with the introduction of trees (relative to the current situation), there is an equivalent relative increase in vegetation for the two additional scenarios (2 and 3) of approximately 4%. However, in scenario 3 trees with denser canopy replace trees of less dense canopy as in scenarios 1 and 2.

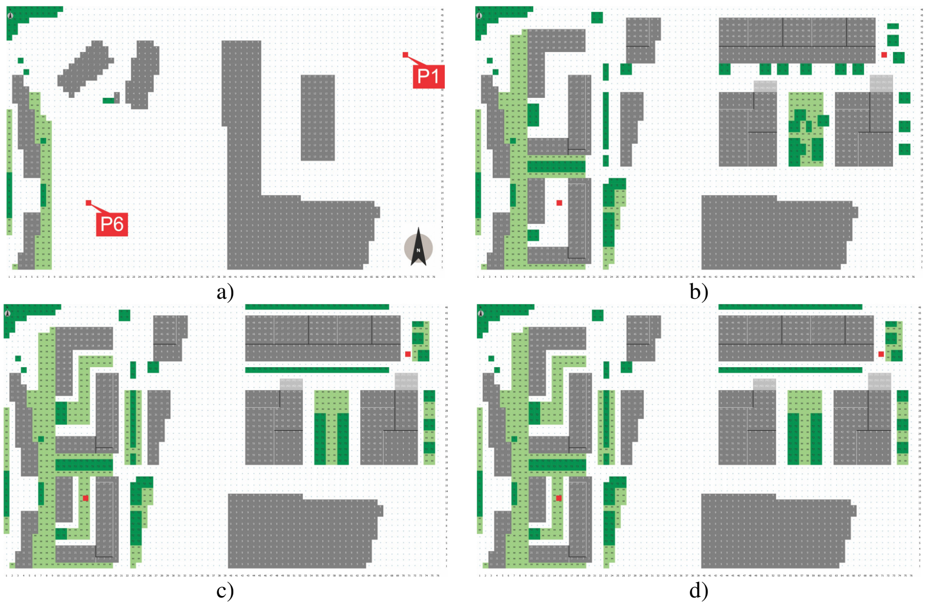


Figure 7: Configurations of the simulated scenarios – original scenario with receptors and scenarios 1-3

Results

Depending on the location of each receptor used for analysis, different results will come out. In general, ambient temperature changes resulting from the inclusion of vegetated areas and from a better distribution of trees (scenario 3) yielded reductions ranging 1.4-2.2°C, relative to the original scenario.

Average air temperature for the whole area dropped consistently by 0.6°C in scenario 1, 0.7°C in scenario 2 and 1.2°C in scenario 3, promoting changes in the whole thermal field of the selected area (Fig. 8).

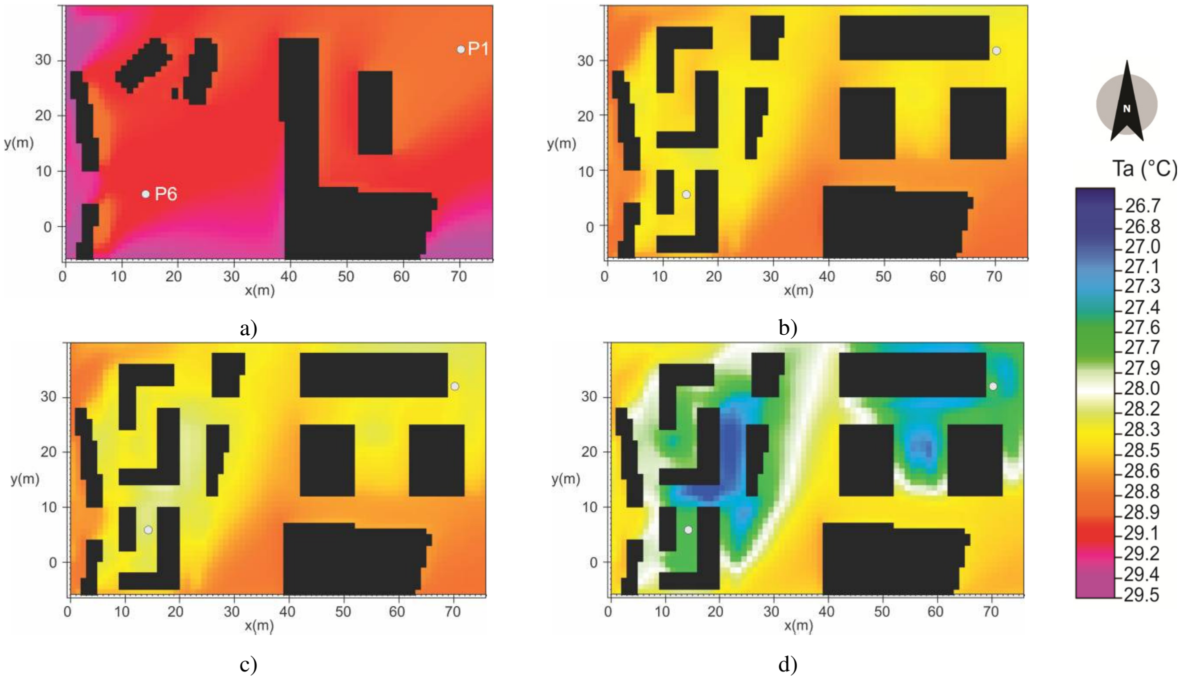


Figure 8. Thermal image –a) original conditions; b) Scenario 1; c) Scenario 2; and d) Scenario 3

CONCLUSIONS

In view of global warming trends and considering the formation of urban heat islands, effective tools that could aid urban interventions with their anticipated effects are of the utmost importance. In this sense, ENVI-met is a relevant tool for urban design studies.

The case-studies presented in this paper have some limitations with regard to aspects such as: the types of trees used (standard trees from the software database were adopted); the disregard of topographical factors and differing surface albedos, the use of orthogonal grids (all aspects limited by the ENVI-met version used); and the calibration procedure based on a limited span of daytime hours. However, results should be interpreted as overall trends from the introduction of particular urban design aspects, in our case, vegetation.

Results suggest a significant potential of greenery introduction in lowering air temperature in urban areas. In São Paulo, a 44% increase in vegetation (green corridor) lead to an overall temperature drop of 1.2°C on the evaluated street. In Geneva, a similar temperature reduction in the evaluated area was found when morphology modifications were introduced alongside a vegetation increase of 12%. In Paris, an increase in vegetation with an alternative distribution of trees yielded an overall drop in air temperature in the evaluated area about 0.6°C. It should be stressed that the percentage of vegetation refers in each case to differing surface areas (particular streets, as in the case of São Paulo, or street blocks as in Geneva and Paris).

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