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ORIGINAL PAPER

The impact of different cooling strategies on urban air temperatures: the cases of Campinas, Brazil and Mendoza, Argentina

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Abstract This paper describes different ways of reducing urban air temperature and their results in two cities: Campinas, Brazil—a warm temperate climate with a dry winter and hot summer (Cwa), and Mendoza, Argentina—a desert climate with cold steppe (BWk). A high-resolution microclimate modeling system—ENVI-met 3.1—was used to evaluate the thermal performance of an urban canyon in each city. A total of 18 scenarios were simulated including changes in the surface albedo, vegetation percentage, and the H/W aspect ratio of the urban canyons. These results revealed the same trend in behavior for each of the combinations of strategies evaluated in both cities. Nevertheless, these strategies produce a greater temperature reduction in the warm temperate climate (Cwa). Increasing the vegetation percentage reduces air temperatures and mean radiant temperatures in all scenarios. In addition, there is a greater decrease of urban temperature with the vegetation increase when the H/W aspect ratio is lower. Also, applying low albedo on vertical surfaces and high albedo on horizontal surfaces is successful in reducing air temperatures without raising the mean radiant temperature. The best combination of strategies—60 % of vegetation, low albedos on walls and high albedos on pavements and roofs, and 1.5 H/W—could reduce air temperatures up to 6.4 °C in Campinas and 3.5 °C in Mendoza.

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1 Introduction

Cities have an impact, to a greater or lesser extent, on every climatic parameter of their local environments. An increase in air temperatures intensifies urban energy consumption for cooling and augments peak electricity demands during the summer (Synnefa et al. 2007a). Also, cities contribute to problems of pollution, human comfort levels, and health issues, as well as deepen the urban footprint (Kolokotroni and Giridharan 2008; Mirzaei and Haghighat 2010; Santamouris et al. 2011).

The increase in urban temperatures is due to several factors that can be classified as controllable and uncontrollable (Rizwan et al. 2008). As for the controllable variables, we can mention anthropogenic heat release, the storage of solar radiation in buildings, urban structures and road morphology that restrict airflow, thermo-physical properties of the materials, and the green/sealed area ratios that regulate the evapotranspiration. Uncontrollable variables are related to the microclimatic characteristics of the area, such as solar radiation, cloud cover percentage, wind speed and direction, etc.

Around the world, the different strategies for the reduction of urban warming are based on two principles: increasing the green coverage and working on the thermophysical properties (albedo, emissivity, roughness, etc.) of the urban materials. (Doulos et al. 2004; Synnefa et al. 2006; Synnefa et al. 2007b; Zinzi and Agnoli 2012; Alchapar et al. 2013).

Increasing vegetation in the urban environment, like tree planting campaigns, urban parks, green roofs, and green walls have been studied and also show benefits for urban cooling (Kolokotroni and Giridharan 2008; Shashua-Bar et al. 2010).

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Studies by Emmanuel and Loconsole (2015) show that when green roofs are applied on a city scale, they may reduce the average ambient temperature between 0.3 and 3 °C.

Several studies indicate that cool materials applied to the opaque surfaces of buildings and urban structures contribute significantly to diminishing the urban surface warming and improving urban environmental quality (Bretz et al. 1998; Santamouris et al. 2011; Santamouris 2014; Alchapar et al. 2014; Urban and Kurt 2010). Akbari et al. (2009) publish that the application of cool materials on roofs, as well as on pavements, can increase the urban albedo about 0.1 on average and decrease the peak ambient temperature in urban areas by 1 °C. However, increasing the albedo in high-density urban canyons can cause serious overheating problems. Large amounts of reflected radiation can be absorbed by surrounding surfaces and subsequently increase street temperatures (Shashua-Bar et al. 2012; Synnefa et al. 2006; Taha et al. 1988; Yaghoobian and Kleissl 2012).

Other studies comparing the effects of using combined levels of higher vegetation and cool materials have defined the boundaries and conditions under which a better performance can be reached (Karlsson 2000; Yilmaz et al. 2007; Spangenberg et al. 2008; Bowler et al. 2010; Correa et al. 2012; Park et al. 2012; Montezuma et al. 2014; Middel et al. 2015; Abreu-Harbich et al. 2015).

Although several studies indicate that applied urban climatology in city planning is in its initial stages, this is altogether promising. The effectiveness of these applications depends upon understanding the consequences of these strategies on the urban layout in their respective climates (Hebbert and Jankovic 2013; Hebbert 2014).

Under this framework, this study was done as part of an international cooperation project between Argentina and Brazil (National Scientific and Technical Research Council—CONICET and Research Support Foundation of the State of São Paulo—FAPESP). The aim was to investigate the results of the application of the most popular strategies for reducing urban air temperatures in two Latin American cities: Campinas, Brazil—warm temperate climate with dry winter and hot summer (Cwa) and Mendoza, Argentina—desert climate with cold steppe (BWk)—(Köppen classification). The diverse strategies analyzed were combinations of albedo of opaque surfaces, vegetation percentage, and H/W aspect ratio. In addition, the behavior of the mean radiant temperature (Tmrt) was assessed in the urban canyons in order to verify if increasing the albedo would cause overheating problems. The final goal of this paper is to detect, in quantitative terms, which strategies are more effective in each city. Since both cities are growing similarly and have comparable technological and economic capabilities, this information will promote a direction at improvements in urban thermal conditions.

2 Methodology

In order to quantify the effects of modifying the vegetation percentage, the albedo level of urban surfaces, and the H/W aspect ratio on the air temperatures of both cities, Campinas and Mendoza, the following procedure was developed:

An area in each city was selected as a case study In each area, microclimatic conditions were monitored in summer. Two numerical models in the ENVI-met simulator were developed to represent the urban morphology and to predict the air temperature (Ta) and the Tmrt behavior of the studied areas. The simulated air temperature curves were adjusted to correspond with the microclimatic curves monitored at each site. Finally, by means of ENVI-met, the different strategies were applied in order to improve the thermal quality of the urban spaces in both cities.

2.1 Features of cities and the selection of case studies

The metropolitan area of Campinas (22° 53′ 20″ S, 47° 04′ 40″ W) has an average altitude of 680 m and is located in the southeast of Brazil with an approximate surface area of 794 km^2 and a population of 1,144,862 (IBGE 2015). The climate of the city is Cwa (Köppen classification), warm temperate climate with dry winters and hot summers (Kottek et al. 2006), 1372-mm annual rainfall, and 1048.25 W/m^2 average of maximum daily solar radiation in the summer. Annual wind speed is 2.7 m/s (h = 10 m) predominantly in the southeastern direction. The average yearly temperature is 21.40 °C, with average highs at 27.10 °C and average lows at 15.60 °C (Cepagri 2014).

The metropolitan area of Mendoza (32° 54′ 48″ S, 68° 50′ 46″ W) has an average altitude of 750 m and is located in the central-western region of Argentina with a surface area of 368 km^2 and an approximate population of 1,086,000. The climate of the city is BWk (Köppen classification), desert climate with cold steppe/desert (Kottek et al. 2006), with relatively low atmospheric humidity percentages, 218 mm of annual rainfall, high heliophany, and 1022 W/m^{2}average of maximum daily solar radiation in the summer (Weather Analytics, n.d.). There is an annual wind speed of 1.7 m/s (h = 10 m), predominantly from the southeast. The annual average temperature is 16.50 °C, where the average high is 24.50 °C and the average low is 9.60 °C (Mendoza Aero Observations 2014).

2.1.1 Area of study

The case studies were selected as necessarily representative of the morphological features of residential areas in both cities. These urban areas are expanding as low density, discontinuous, and scattered (State of the World's Cities 2013), which correspond with the growth patterns of Latin American cities. For this study, two urban sectors of low building density were selected: one in Campinas, Brazil and the other in Mendoza, Argentina.

The area studied in the municipality of Campinas is within the central region of the city, a section with low horizontal building density and mixed zoning (residential and commercial). The buildings have an average height of 4 m with a maximum height of 7 m. There is approximately 20 % vegetation in the urban canyons. There are vegetative species of medium size in the urban canyons, between 7- and 10-m high, with sibipiruna *Caesalpinia peltophoroides*, butterfly tree *Bauhinia variegata*, and small size willow trees *Salix babylonica*, being the most prominent. There is an organic urban layout with pavement and sidewalks composed of 50 % yellow and reddish limestone and 50 % concrete. The roofs are predominately composed of red tiles and sloped with a small percentage consisting of metal sheets. The materials that make up the vertical surfaces are stone painted in various tones.

The area studied in Mendoza is located in the southeast of the metropolitan area, a region with low horizontal building density and mixed zoning (residential and commercial). The buildings have an average height of 4 m, with a maximum height of 9 m. There is approximately 60 % vegetation in the urban canyons. There are vegetative species of medium size between 10- and 15-m high, including mulberry *Morus alba* and a small number of *Platanus hispánica*. The materiality of the structures in the horizontal plane consists of vehicular concrete pavement and pedestrian pavement of yellow, red, and black limestone tiles. Eighty percent of the roofs are flat and made of solid slabs with a roofing membrane, while the other 20 % are sloped and made of metal sheets or red tiles. The facades of the buildings are made of exposed brick, dark flagstone, or fine plaster painted in various tones. According to LCZ classification (Stewart et al. 2013) Campinas correspond to LCZ 6b and Mendoza to LCZ 6a.

See Table 1 for the characteristics of each case study. In both cities, the area studied has a surface area of 210 m × 210 m. The two selected sections represent low-density regions and proximity to the urban center.

One critical issue in selecting the study areas is the different solar orientation of the canyons. This implies that both areas receive different amounts of sun radiation throughout the day. Nevertheless, this factor is not so relevant when the urban canyons are shallow.

To overcome the particular orientations of the studied areas, each city was simulated with the conditions of the other, for example, Campinas was simulated with an orientation of 348° N and Mendoza with 35° N. Then, the results on temperature differences were compared. They show that the orientation of these particular areas has a minimal impact on air temperature, lower than 0.3 °C in both cities. Based on this assessment, it was stated that, for these particular cases, the difference between the orientations of both cities will not strongly influence air temperature prediction.

2.2 Data climatic input and microclimatic data collection

The microclimatic conditions were monitored during the summer in both selected urban canyons in order to calibrate the simulated air temperature curve to the air temperature of the current case. In Campinas, the data assessed was collected on February 21, 2013. On this day, data from meteorological station (Campinas Agronomic Institute (IAC)) are as follows: maximum daytime temperature is 31.4 °C, minimum daytime temperature 18.2 °C, average temperature 23.9 °C, maximum global solar radiation 925.0 W/m^2, and average relative humidity 66.8 %.

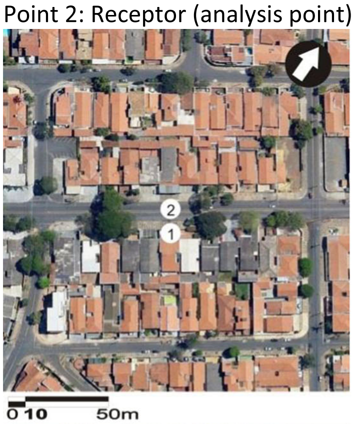
In Mendoza, the data assessed was collected on January 14, 2010. On this day, the data from meteorological station are as follows: maximum daytime temperature is 31.0 °C, minimum daytime temperature 22.0 °C, average temperature 26.0 °C, maximum global solar radiation 1181.0 W/m^2, and average relative humidity 39 % (Mendoza Aero Observations 2014).

In addition, other climatic variables are needed to set up the boundary conditions in ENVI-met model to run the simulation (See Table 2). They are the direction and speed of the wind and the specific humidity of atmosphere. Wind direction and speed data was collected at a height of 10 m by official local urban meteorological stations. In Campinas, the data was collected at Campinas Agronomic Institute—IAC, at an approximate distance of 2.5-km northeast of the study area. The data in Mendoza was collected by the Observatory of Francisco Gabrielli Airport at an approximate distance of 4 km west of the study area.

The specific humidity data at 2500 m was collected in Brazil by the Marte São Paulo Airport (station number—83779, Mart Civ Observations) and in Argentina by the Francisco Gabrielli Airport (station number—87418, Mendoza Aero Observations) in collaboration with the University of Wyoming.

The collection of microclimatic variables was realized through fixed station points near the center of the area studied (Table 1). These findings were collected at a height of 2.1 m. The measurement equipment were as follows:

Table 1 Description of Campinas and Mendoza city

CAMPINAS - BRAZIL	MENDOZA - ARGENTINA
Vegetation percentage in canyon: 20 %	Vegetation percentage in canyon: 60 %
Roofs albedo: 0.30	Roofs albedo: 0.30
Pedestrian pavement albedo: 0.30 - 0.40	Pedestrian pavement albedo: 0.40
Vehicular pavement albedo: 0.20	Vehicular pavement albedo: 0.30
Façade albedo: 0.20	Façade albedo: 0.20
H/W evaluated streets: 0.22	H/W evaluated streets: 0.30
Width of evaluated street (W): 12 m	Width of evaluated street (W): 12 m
Width of evaluated sidewalk (W): 10 m	Width of evaluated sidewalk (W): 8 m
Mean height building of evaluated street (H): 5 m	Mean height building of evaluated street (H): 6 m
Point 1: Set point	Point 1: Set point
Point 2: Receptor (analysis point)	Point 2: Receptor (analysis point)
	
	

TESTO 174H (temperature accuracy ±0.5 °C from −20 to +70 °C and humidity accuracy ±3 % from 2 % RH to 98 % RH, ±1 digit +0.03 % RH/K) in Campinas and HOBO® H08-003-02 (temperature accuracy ±0.7 °C from +21 °C and humidity accuracy ±5 % from +5 °C to +50 °C) in Mendoza. Both pieces of equipment were installed on a sidewalk near the center of the block, inside of a radiation shield (WMO 2006).

2.3 ENVI-met simulation and adjustment

The microclimate of this study was simulated with the ENVI-met V3.1 (beta) program that predicts the interactions between the urban surfaces, vegetation, and atmosphere using virtual models that include airflow, turbulence, temperature profile, and humidity along with radiation fluxes (Bruse and Fleer 1998).

ENVI-met is a model that seeks to reproduce the major processes in the atmosphere that affect the microclimate on a well-founded physical basis (i.e., the fundamental laws of fluid dynamics and thermodynamics). This tool has been validated worldwide (Emmanuel et al. 2007; Krüger et al. 2011; Chow et al. 2011; Wania et al. 2012; Fröhlich and Matzarakis 2012; Yang et al. 2013; Middle et al. 2014). Nevertheless, ENVI-met version 3.1 has some limitations, e.g., it does not take into account the thermal mass of walls and roofs (ENVI-met 3.1 Manual n.d.; Bruse and Fleer

Table 2 Input parameters and input model area for ENVI-met simulation

Dates		Campinas	Mendoza
Main data	Wind speed in 10 m ab. Ground [m/s]	1.9	3
	Wind direction (0′ N; 90′ E;180′ S; 270′ W)	135	150
	Roughness Length z0 at reference point	0.1*	0.1*
	Initial temperature atmosphere [K]	295	300
	Specific humidity in 2500 m [g water/kg air]	8.2	2.8
	Relative humidity in 2 m [%]	66	28
Building	Inside temperature [K]	298	299
	Heat transmission walls [W/m^{2}K]	2.8	2
	Heat transmission roofs [W/m^{2}K]	2	0.76
	Albedo walls	0.2	0.2
	Albedo roofs	0.3	0.3
Soil data	Initial temperature upper layer (0–20 cm) [K]	310	300
	Initial temperature middle layer (20–50 cm) [K]	310	305
	Initial temperature deep layer (below 50 cm) [K]	310	305
	Relative humidity upper layer (0–20 cm) [%]	50*	50*
	Relative humidity middle layer (20–50 cm) [%]	60*	60*
	Relative humidity deep layer (below 50 cm)	60*	60*
Solar adjust	Factor of shortwave adjustment	1.5	1.5
Number of grids		x-Grids: 70	x-Grids: 70
		y-Grids: 70	y-Grids: 70
		z-Grids: 30	z-Grids: 30
Size of grid cell in meters		dx: 3	dx: 3
		dy: 3	dy: 3
		dz: 3	dz: 3
Plants		Grass*: height 0.63 m. LAD1: 0.30; LAD6: 0.30; LAD10: 0.30 (m^2/m^3)	Tree 15 m light*: height 15.0 m. LAD1: 0.04; LAD6: 0.150; LAD10: 0.00 (m^2/m^3)
		Hedge dense*: height 6.0 m. LAD1: 2.50; LAD6: 2.50; LAD10: 1.50 (m^2/m^3) Tree 10 m dense*: height 10.0 m. LAD1: 0.075; LAD6: 1.150; LAD10: 0.00 (m^2/m^3)	Tree 15 m very dense*: height 15.0 m. LAD1: 0.15; LAD6: 2.15; LAD10: 0.00 (m^2/m^3)
Pedestrian pathways		Brick road (red stones)*: albedo 0.9 Pavement (concrete)*: albedo 0.4	Cement concrete: albedo 0.4
		Gravel road: albedo 0.9	
Vehicular pathways		Asphalt road*:0.2	Pavement (concrete): albedo 0.3

Cities of Campinas and Mendoza. The parameters with "*"are default values of ENVI-met

1998; Huttner 2012), and it can only calculate idealized models of diurnal variations for different meteorological parameters like wind speed and direction, air temperature, air humidity, and solar irradiation at the boundaries of the model area. Dynamic measurements taken throughout the day cannot be entered into the model. (Huttner 2012).

ENVI-met requires two main input files: a configuration file, which contains all initial values; and an input file, which permits the digitalization of the study area specifying the location of buildings, vegetation, soil, surface variation, and collection points. The configuration files have the meteorological data that initiates the model. ENVI-met input variables are 10-m (m/s) wind speed, wind direction, roughness (Zo), starting atmospheric temperature, specific humidity at 2500 m (g water/kg air), relative humidity at 2 m (%), internal temperature, temperature, and soil humidity.

The following items describe the input variables for the ENVI-met program and the prospective scenarios for the urban microclimate analysis. The phase described in Sect. 2.2 was important for the initialization of simulator and the calibration of the end results.

2.3.1 Input data

The ENVI-met program consists of a three-dimensional model of a unidirectional nesting area that extends to a height of 2500 m. The three-dimensional model is sub-divided in grid cells (w, y, and z), and the size of each cell is defined by resolution. Each grid cell contains information about soil, buildings, vegetation, and open spaces (Bruse and Fleer 1998; Wania et al. 2012).

In order to simulate the study areas, a grid resolution of 3 × 3 × 3 m was utilized, totaling a grid area of 70 × 70 × 30 (x, y, z), which correspond with the areas studied, composing an urban section of 210 m × 210 m (see Table 2).

In order to maintain numeric stability, five nesting grids were inserted around the model (Yang et al. 2013). The simulations started at 21-h local time in both cities: February 23, 2013 in Campinas and January 14, 2010 in Mendoza. Five days (5 cycles) were simulated, and a stability of the model was reached in the fourth cycle.

For vegetation, a database that contains the default ENVI-met library was used for its recognition and local characterization. By visiting the different study areas, differences in specific vegetation were observed as follows: weeds, small and medium size trees, and bushes. Therefore, the default value was used for the leaf area index (default leaf area density (LAD)) from ENVI-met for the plants (see Table 2).

We highlight that the vegetation model in the ENVI-met includes leaf temperatures, evapotranspiration, and shading. These characteristics interact with the atmospheric model, as well as with soil and radiation models. Plants in ENVI-met 3.1 are modeled as vegetation columns (ENVI-met 3.1 Manual n.d.; Huttner 2012; and Mohamad et al. 2010) and are characterized by diverse parameters, in which LAD is one of them. The LAD profile changes accordingly with the height of the trees. The LAD profiles provided by ENVI-met are drawn by hand and based on only a few reference profiles. Although this seems limited, it is a very reliable way of measurement (ENVI-met 3.1 Manual n.d.).

In this research, trees were taken from the database; but, in addition, an analytical approach was used to compare the LAD profile selected with the real case. According to Meir et al. (2000), it is possible to adjust the LAD profile using photography. In this study, we took a hemispherical digital image of the evaluated urban canyon and calculated the sky view factor value (SVF). Then we adjusted the SVF value measured in the real case with those provided by the simulation in order to validate the selection of trees from simulator database.

In order to determine the thermal properties of the buildings in Campinas, the values presented in the local standard were adopted (Brazil ABNT NBR 15220-3 2005). We used the measured values registered in reference materials for those in Mendoza. The interior building temperature in Campinas was set at 24.85 °C and in Mendoza at 25.85 °C, since they are the mean temperature of the evaluated day in each city. It is important to keep in mind that buildings common in both cities are neither air conditioned nor thermally insulated. The albedo adopted for walls was 0.2 and for ceilings 0.3 in both cities (Sailor and Fan 2002).

All input parameters are shown in Table 2.

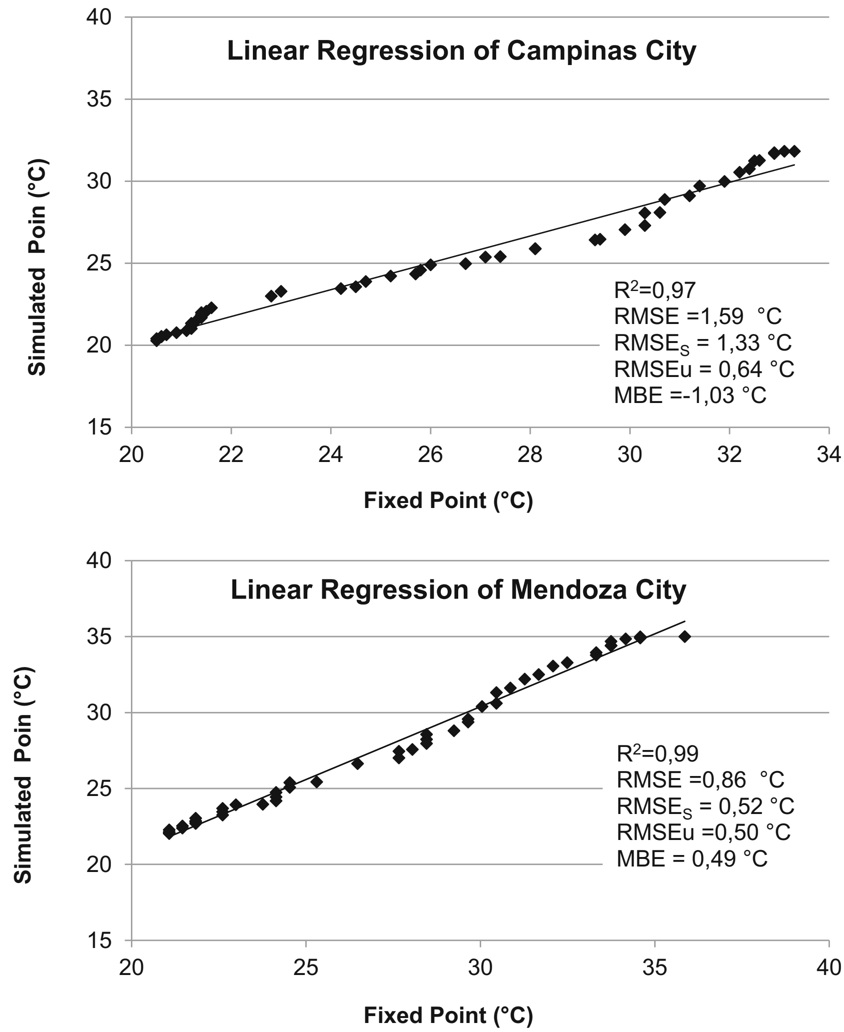
2.3.2 Calibrating ENVI-met

The simulated air temperature curve with the measured curve of the day studied was compared in order to validate the results from the numerical model in the two urban areas (Fig. 1). Comparison statistics reported here include root mean square error (RMSE), with both systematic ($RMSE_S$) and unsystematic ($RMSE_U$) components; the mean bias error (MBE); and the coefficient of determination (R^2) that has been formally defined in Willmott (1981) and Jacobson (1999).

The RMSE provides information on the short-term performance of a model by allowing a term-by-term comparison of the actual difference between the estimated value and the measured value. The smaller the value, the better the model's performance. A drawback of this test is that a few large errors in the sum can produce a significant increase in RMSE. In addition, the test does not differentiate between underestimation and overestimation. The MBE provides information on the long-term performance of a model. A positive value gives the average amount of overestimation for the estimated values and vice-versa. The smaller the absolute value, the better the model performance. A drawback of this test is that an overestimation of an individual observation will cancel an underestimation in a separate observation (Ma and Iqbal 1984; Stone 1993).

A larger systematic error ($RMSE_S$) typically indicates that the model has a problem with parameter values or

Fig. 1 Validation test of set point 1. Scatter plot and linear regression of air temperature curve (°C) of the numeric model (ENVI-met) and fixed point



the theoretical model, whereas a large unsystematic error ($RMSE_U$) is associated with the inability to cope with the variability in the observations, which may be related to the "randomness" of the conditions observed. Ideally, the systematic error would be the smaller of the two errors. (Grimmond et al. 2010).

The results show a similar correspondence between the fixed point and the simulated point in both cities (Fig. 1). The R^2 indicates a good accuracy of the model, Campinas = 0.97 and Mendoza = 0.99. There are also acceptable low magnitudes of RMSE and their components—$RMSE_S$ and $RMSE_U$—suggesting that these base scenarios are largely accurate. MBE in Campinas is equal to −1.03 °C, the negative magnitude, which indicates the average amount is underestimated. On the contrary, MBE is overestimated by 0.49 °C in Mendoza.

Table 3 details the characterizing statistics and compares the data from the collection point (fixed point) with the ENVI-met (simulation point).

2.4 Simulation scenarios

Different study scenarios were simulated in order to analyze the specific thermal behavior of the study areas. The study evaluated the variation of urban air temperatures produced by changing three aspects: a deepening of the urban canyon—H/W aspect ratio (Ali-Toudert

Table 3 Minimum, maximum and mean temperatures and thermal amplitude of fixed collection point and the numerical model of simulation (ENVI-met) for the cities of Campinas and Mendoza

Temperature (°C)	Set point Campinas (1)		Set point Mendoza (1)	
	Fixed point	Simulation point	Fixed point	Simulation point
Min	20.5	20.5	21.0	22.0
Max	33.0	32.0	36.0	35.0
Mean	26.0	25.0	27.0	28.0
Amplitude	13.0	12.0	15.0	13.0

2005; Ali-Toudert and Mayer 2006; Oke 2006); vegetation (Bowler et al. 2010; Emmanuel and Loconsole 2015); and albedo (Akbari et al. 2009; Santamouris et al. 2011). The scenarios were defined considering the following variables:

2.4.1 Height/width of the urban canyon—H/W aspect ratio (average height of urban canyon/width of urban canyon)

- Low H/W: The urban canyon has a geometry of the current scenarios (H/W of Campinas = 0.2; H/W of Mendoza = 0.3).
- High H/W: The urban canyon is equal to 1.5 for both cities.

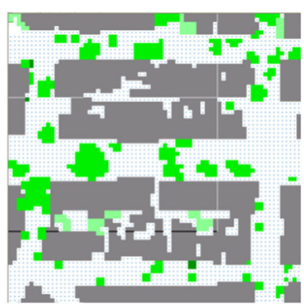
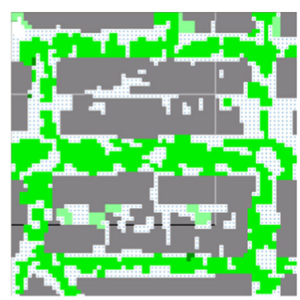
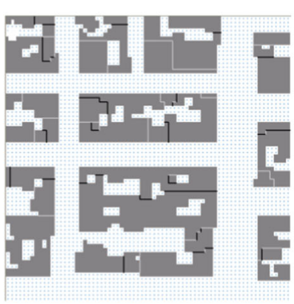
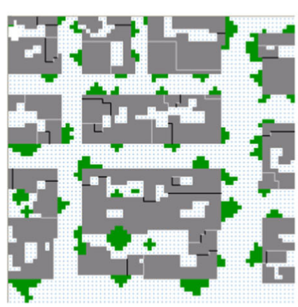
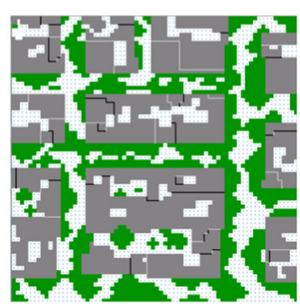
2.4.2 Vegetation

- Zero percent of vegetation in the canyon: complete absence of vegetation in the canyon
- Twenty percent of vegetation in the canyon: corresponding to the current situation in Campinas
- Sixty percent of vegetation in the canyon: corresponding to the current situation in Mendoza (see Table 4)

2.4.3 Albedo

- Low albedo: The horizontal and vertical surfaces were simulated with low albedo. Campinas: roofs = 0.30, walls = 0.20, pedestrian pathways = 0.20–0.40, and vehicular pathways = 0.20. Mendoza: roofs = 0.30, walls = 0.20, pedestrian pathways = 0.30–0.40, and vehicular pathways = 0.20–0.30.
- High albedo: Increased albedo on horizontal and vertical surfaces in both cities. Campinas and Mendoza were simulated with albedo on roofs and walls = 0.80 and for pedestrian and vehicular pathways = 0.70.
- Combined albedo: The low albedo values for vertical surfaces were maintained, while the values for the horizontal surfaces were increased. Mendoza and Campinas: albedo for walls: 0.20 (low), albedo for the pedestrian and vehicular pathways: 0.70 (high), and roofs: 0.80 (high).

Table 4 ENVI-met maps of study areas (Campinas-Mendoza) according to vegetation percentage

	0% of vegetation in the canyon	20% of vegetation in the canyon	60% of vegetation in the canyon
CAMPINAS			
MENDOZA			

All scenarios are represented in Table 5.

3 Results

The output data from the ENVI-met software were obtained for a given receptor (point 2) at 2.1-m height. See Table 1.

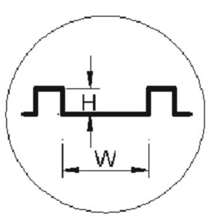
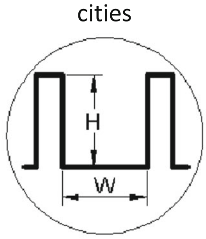
3.1 Normal air temperature distribution from both Campinas and Mendoza

In Fig. 2, air temperatures are shown from all scenarios simulated for both cities: Campinas and Mendoza. Diagonal lines are highlighted within the box plot, demonstrating the corresponding behavior in the current scenarios in each city. Scenario E1.b (low H/W aspect ratio, low albedo, and 20 % vegetation) corresponds to the area studied in Campinas, while scenario E1.a (low H/W aspect ratio, low albedo and 60 % vegetation) corresponds to the area studied in Mendoza.

3.1.1 Independent and dependent variables

The results of the simulations of the 18 analyzed scenarios for each city (36 simulations in total) constitute the range of the statistical analysis. In the "box plot" box diagram, it can be observed that the total collated independent variables (the albedo of the walls, the albedo of the roofs, and the average albedo; the percentage of vegetation; aspect ratio: H/W; and SVF) are similar for both cities studied, which justifies their comparison. (See Fig. 3).

Table 5 Characterization of scenarios studied

			ALBEDO			LCZ
			Low*	High**	Combined***	
LOW DENSITY H/W of Campinas: 0.2 H/W of Mendoza: 0.3 	**% VEGETATION** WITHIN THE STREET CANYON	60%	E1.a *Actual Scenario Mendoza*	E2.a	E5.a	**6.a**
		20%	E1.b *Actual Scenario Campinas*	E2.b	E5.b	**6.b**
		0%	E1.c	E2.c	E5.c	**6.c**
HIGH DENSITY H/W: 1.5 for both cities 	**% VEGETATION** WITHIN THE STREET CANYON	60%	E3.a	E4.a	E6.a	**2.a**
		20%	E3.b	E4.b	E6.b	**2.a**
		0%	E3.c	E4.c	E6.c	**2.a**

*Low albedo: roofs = 0.30, walls = 0.20, pathways pedestrian = 0.20, 0.40, and vehicular = 0.2, 0.3

**High albedo: roofs and walls = 0.80, pathways pedestrian = 0.70, and vehicular = 0.7

***Combined albedo: roofs = 0.80, walls = 0.20, pathways pedestrian = 0.70, and vehicular = 0.7

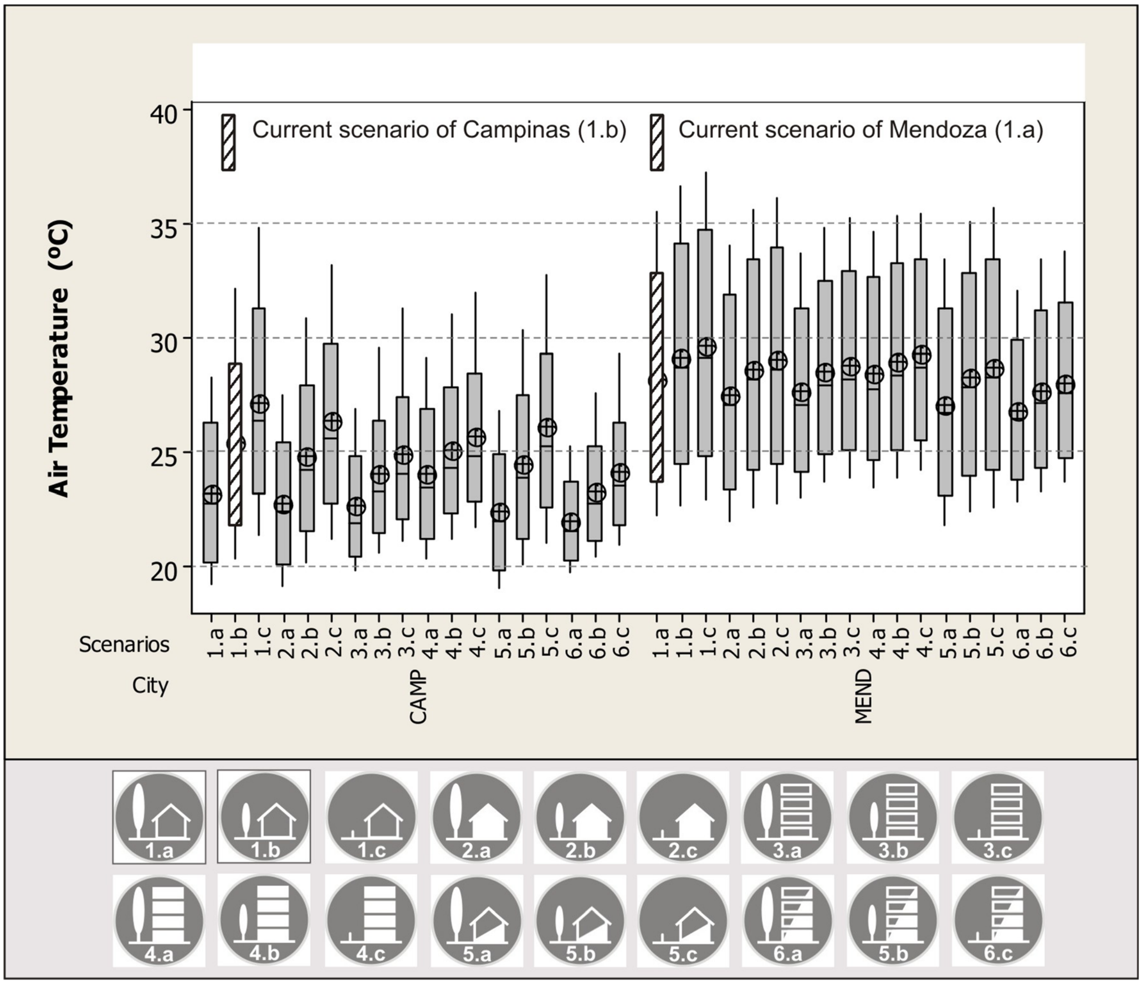


Fig. 2 Normal air temperature distribution (°C) simulated for each scenario in the cities of Campinas and Mendoza

3.2 Impact of strategies with regard to the current scenarios in Campinas and Mendoza cities

Table 6 summarizes the differences in air temperature (ΔTa °C) and in mean radiant temperature (ΔTmrt °C) of the current scenarios in Campinas (E1.b) and Mendoza (E1.a) with respect to the alternative scenarios. The increases in temperature are represented by a positive sign (+), and the decreases are identified with a negative sign (−) for each configuration referring to the current scenario.

Figure 4 shows the ENVI-met software results. The air temperature curve and mean radiant temperature curve, according to H/W aspect ratio was graphed.

3.2.1 Difference in air temperature

In terms of the air temperature, the results show the following:

Scenarios that include 60 % vegetation and a high H/W aspect ratio demonstrate lower urban air temperatures.

Increasing the albedo on all urban opaque surfaces generally diminishes maximum air temperatures. Starting from the current scenarios in each city, in Campinas, this strategy reduces the air temperature approximately by 1 °C in both low and high H/W aspect ratios. In Mendoza, it reduces the temperature by 1.5 °C in low H/W aspect ratio; however, high albedo increases the air temperature 1 °C in high H/W aspect ratio.

In order to come up with a good strategy for the overheating of high H/W aspect ratios, a combined albedo was tested: high albedo on horizontal surfaces and low albedo for the vertical (E.5 and E.6). Starting from the current scenarios in each city, we found that in Campinas, this strategy—high albedo in horizontal surfaces and low albedo in vertical—reduces the air temperature up to 1.8 °C in low H/W aspect ratio and 3.7 °C in high H/W; and in Mendoza, air temperature reduces by 2 °C in low H/W aspect ratio and 3.5 °C in high H/W.

Increased vegetation diminishes air temperature in all scenarios. Table 6 shows that vegetation always improves air

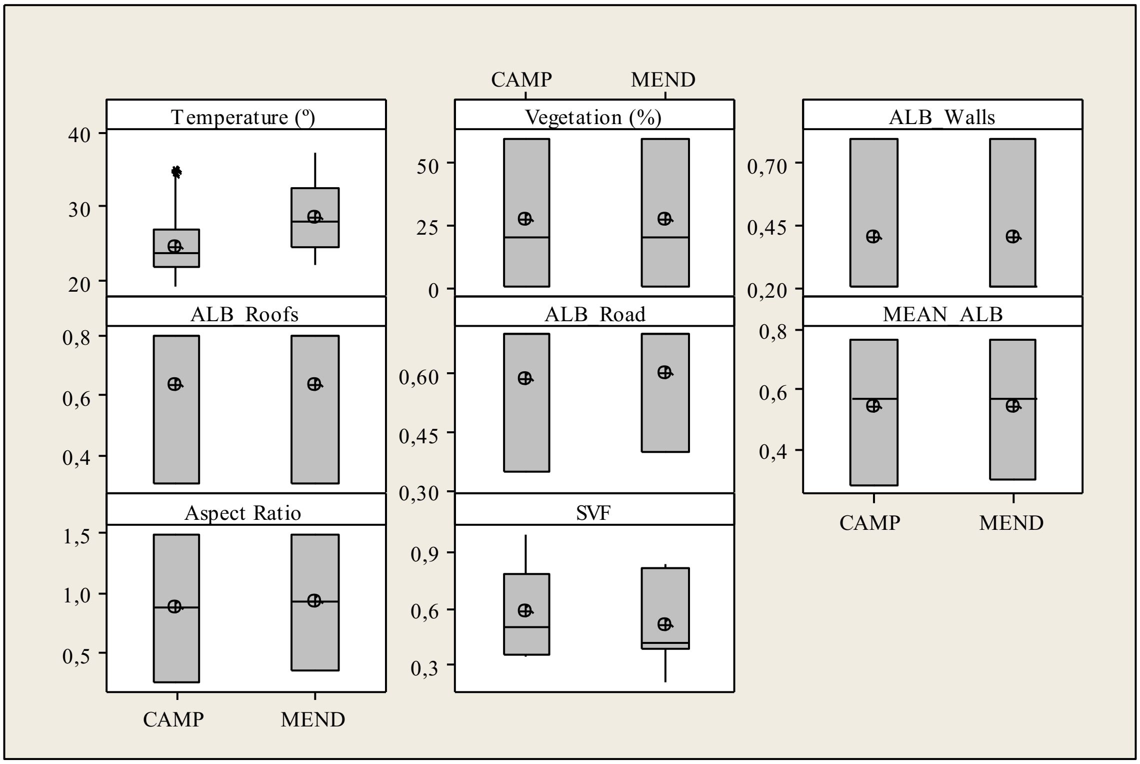


Fig. 3 Dependent and independent behaviors in the designed scenarios for Campinas and Mendoza

temperatures: maximum, average, and minimum. Their thermal benefits, which were verified during the heating period as well as during the cooling period, greatly reduce maximum air temperatures. Starting from the current scenarios in each city, in Campinas, this strategy reduces the air temperature up to 4 °C in low H/W aspect ratio and 5 °C in high H/W aspect ratio. In Mendoza, reductions up to 2 °C for both low and high H/W aspect ratios can be seen.

The high H/W aspect ratio reduces the maximum air temperatures although worsens minimum temperature behavior (see Fig. 4 and Table 6).

3.2.2 Difference in mean radiant temperature

In terms of the mean radiant temperature (Tmrt), Table 6 and Fig. 4 describe the behaviors for all evaluated scenarios. The results show the following:

In all scenarios, Tmrt increases when the H/W aspect ratio, and the albedo levels increase. These increases are more intense in Mendoza than in Campinas. This behavior could be explained by the high presence of solar radiation combined with the tree species used for vegetation in the urban canyons in each city. The tree canopy is more translucent in Mendoza than in Campinas.

Increased vegetation diminishes Tmrt, as well as air temperature in all scenarios. For both H/W aspect ratios assessed, the best Tmrt behavior is observed in scenarios with low albedo and 60 % of vegetation. However, greater reductions in air temperatures are observed in those scenarios that present low albedo on vertical surfaces and high on horizontal surfaces. Therefore, a good strategy for reducing air temperature and controlling Tmrt elevation is to distribute correct albedo levels on appropriately positioned surfaces.

4 Discussion

Based on the thermal and statistical analyses, we observed that increasing the vegetation in any scenario offers the best possibilities for improving urban thermal conditions as highlighted by Shashua-Bar et al. (2012) and Bowler et al. (2010) in their research. Therefore, the increase in the vegetation percentage from 0 to 60 % could decrease the average air temperature in Campinas by 3.9 °C, while in Mendoza the temperature could be reduced by 1.7 °C. It should be pointed out these reductions correspond to the points 2 (receptors) shown in Table 1. These results support the findings of Shashua-Bar et al. (2010), who reported on a reduction of 3 °C on average in the air temperature due to increasing the trees in urban canyons in Athens.

Hence, an increase in vegetation offers benefits for both cities; however, the effect in Campinas would be higher than in Mendoza. This may also have to do with the anatomy and physiology of the tree species in each area. In warm temperate areas, the foliage is denser when compared to drier areas (see

Table 6 Air temperature differences (ΔT °C) and mean radiant temperature differences (ΔTmr) according to vegetation percentage, albedo level, and H/W aspect ratio, with respect to the actual scenarios of the cities of Campinas (E1.b) and Mendoza (E1.a) minimum (min), maximum (max), and average (mean) in degrees celsius (°C)

			CAMPINAS						MENDOZA					
	% VEG.		H/W: 0.2	Δ Ta ºC	Δ Tmr ºC	H/W: 1.5	Δ Ta ºC	Δ Tmr ºC	H/W: 0.3	Δ Ta ºC	Δ Tmr ºC	H/W: 1.5	Δ Ta ºC	Δ Tmr ºC
LOW ALBEDO	60%	T° Min	1.a	-1.1	-1	3.a	-0.5	2	1.a			3.a	0.8	2
		T° Max		-3.9	-7		-5.2	-7					-1.9	2
		T° Mean		-2.3	-1		-2.8	-8					-0.6	0
	20%	T° Min	1.b			3.b	0.2	2	1.b	0.5	1	3.b	1.5	2
		T° Max					-2.6	-4		1.1	19		-0.7	19
		T° Mean					-1.4	-7		1.0	14		0.4	10
	0%	T° Min	1.c	1.0	1	3.c	0.8	3	1.c	0.7	1	3.c	1.7	2
		T° Max		2.7	1		-0.9	-4		1.7	20		-0.3	19
		T° Mean		1.7	9		-0.5	-7		1.5	15		0.6	10
HIGH ALBEDO	60%	T° Min	2.a	-1.2	-1	4.a	0	2	2.a	-0.2	-1	4.a	1.2	2
		T° Max		-4.7	11		-3.0	28		-1.5	17		-0.9	31
		T° Mean		-2.7	4		-1.5	5		-0.7	6		0.3	13
	20%	T° Min	2.b	-0.1	0	4.b	0.8	3	2.b	0.4	0	4.b	1.6	2
		T° Max		-1.3	17		-1.1	30		0	36		-0.2	46
		T° Mean		-0.6	5		-0.4	6		0.4	22		0.8	24
	0%	T° Min	2.c	0.8	1	4.c	1.3	3	2.c	0.6	0	4.c	2.0	2
		T° Max		1.1	17		-0.1	30		0.6	36		-0.1	46
		T° Mean		0.9	17		0.2	6		0.8	23		1.1	24
COMBINED ALBEDO	60%	T° Min	5.a	-1.3	-1	6.a	-0.8	2	5.a	-0.4	-1	6.a	0.6	1
		T° Max		-5.3	10		-6.4	11		-2.1	13		-3.5	15
		T° Mean		-3.1	3		-3.4	-6		-1.2	3		-1.4	2
	20%	T° Min	5.b	-0.3	0	6.b	0	2	5.b	0.2	0	6.b	1.1	1
		T° Max		-1.8	16		-3.7	14		-0.5	31		-2.1	31
		T° Mean		-1.0	5		-1.9	-5		0.1	19		-0.6	14
	0%	T° Min	5.c	0.7	0	6.c	0.7	2	5.c	0.4	0	6.c	1.5	2
		T° Max		0.6	17		-1.8	14		0.1	31		-1.8	31
		T° Mean		0.6	17		-0.8	-5		0.5	20		-0.1	15

Table 2). Although the urban morphology and tree disposition are similar in both cases, the differences in the magnitude of temperature reduction could be explained by the interactions of tree anatomy and physiology with other variables as solar radiation, wind speed, absolute humidity, etc. in each city.

Previously, we highlight that the vegetation model in the ENVI-met includes leaf temperatures, evapotranspiration, and shading. In this research, trees were taken from the database; but, in addition, an analytical approach was used to compare the LAD profile selected with the real case. In this way, we adjust the morphology of trees but not their physiology.

In summary, ENVI-met is capable of capturing the physiological effects of a variety of tree species in the prediction of air temperature. However, in this study, the effects are strictly related with the LAD value.

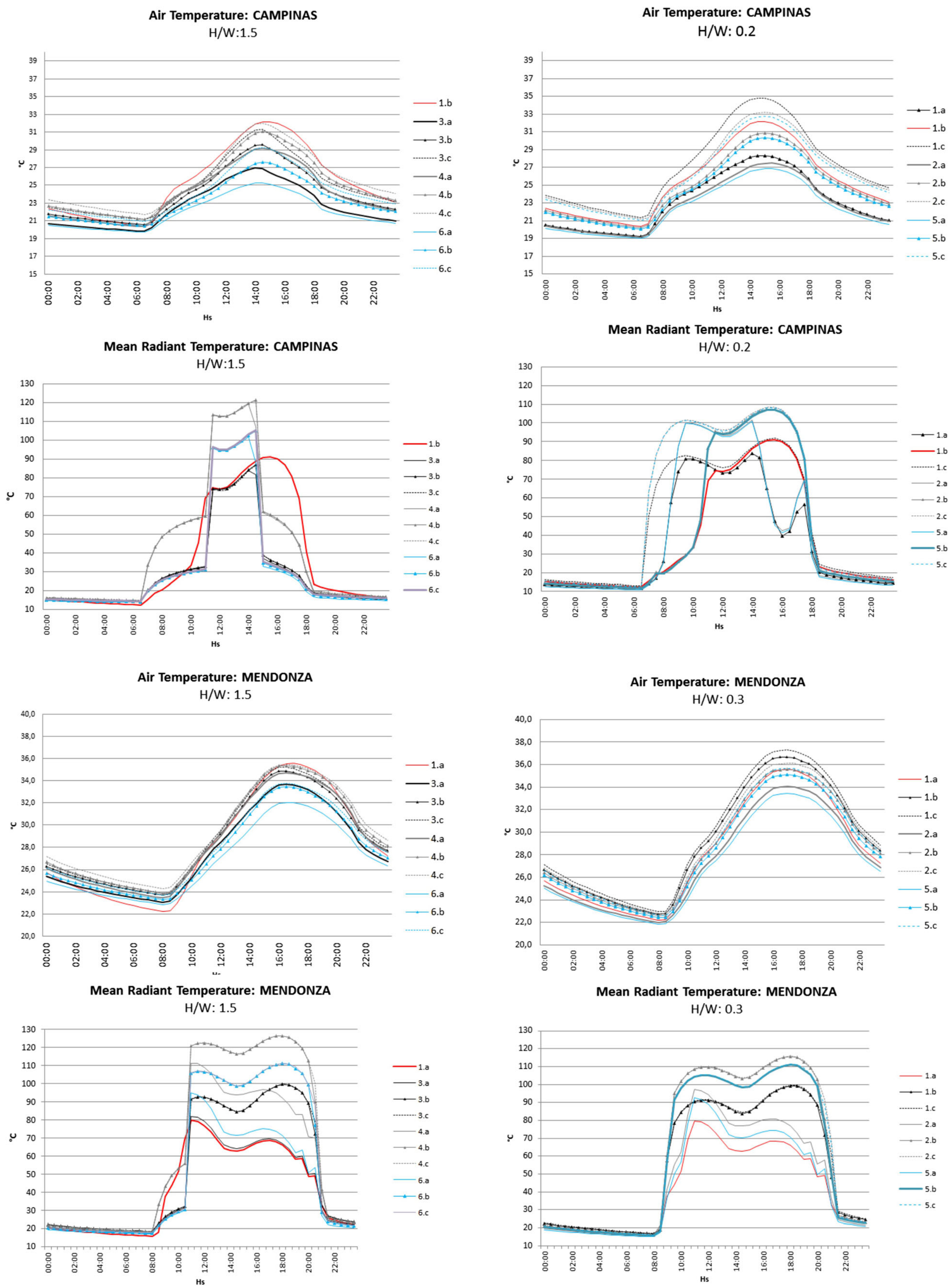


Fig. 4 Comparison of thermal behavior of Campinas and Mendoza scenarios: *Ta °C* air temperature and *Tmr °C* mean radiant temperature

Concerning the use of albedo, results show that increasing the albedo of the urban-building environment would improve thermal conditions for exterior spaces mainly by decreasing the maximum temperatures, when combined with scenarios of vegetation that are greater than 20 %. In Campinas, when the urban albedo increases 0.1, the peak ambient temperature decreases 1.3 °C, and in Mendoza, it decreases by 0.7 °C. This magnitude of reduction in air temperature agrees with findings at an international level. In the 100 most populated cities, Akbari et al. (2009) affirm that raising albedo of urban surfaces (roofs and pavements) by about 0.1, on average, can reduce the summertime urban temperature by 1 °C and improve air quality.

However, this work emphasizes that the change in albedo for vertical surfaces—facades—is a decision that should be analyzed in each particular case. Accordingly, for urban renewal projects or new neighborhoods that do not include an increase of vegetation, the best alternative is to increase albedo for horizontal surfaces and decrease it for vertical ones in both cities (see E5.c; E6.c in Table 6). It is interesting to contrast these results with the research of Erell et al. (2014) who reported that the extensive use of high albedo materials in canyon surfaces—in warm climate cities—may lower air temperature but could increase radiative head loads. As a result, pedestrian thermal comfort may be compromised. This was also highlighted by Yaghoobian and Kleissl (2012), who report that increasing pavement solar reflectivity from 0.1 to 0.5 increases annual cooling loads up to 11 % for a four-story office building in Phoenix, Arizona. However, these findings were assessed in urban canyons without trees. This research advises the use of low albedo on vertical surfaces and high on horizontal surfaces as a strategy for reducing urban canyon temperature and controlling the mean radiant temperature. In addition, this paper demonstrates that high albedo in pavements and roof combined with 60 % of vegetation in urban canyons is an effective way to reduce temperature.

Studies of Yaghoobian and Kleissl (2012), Bouyer et al. (2011), and Strømann-Andersen and Sattrup (2011) indicate the importance of evaluating the urban microclimate influence and not relying on satellites. The diversity of urban landscapes and designs means that only local simulations for specific neighborhoods and urban climates can elucidate the exact effect of reflective pavement implementation.

Regarding the H/W aspect ratio, increasing shadow and thermal mass lowers the maximum temperatures of exterior spaces in all scenarios. Consistent with our results, Strømann-Andersen and Sattrup (2011), as well as Yaghoobian and Kleissl (2012) show that HVAC demands in buildings decreases with an increase of H/W aspect ratio due to greater shadowing. However, densification worsens urban thermal behavior during the cooling period by increasing minimum temperatures.

Concerning the cities evaluated in this study, for Campinas, a greater H/W aspect ratio lowers average air temperatures in 8 of the 9 scenarios analyzed (i.e., all of the high density scenarios that were tested except the high albedo scenario without vegetation—E4.c). The best scenario for the Brazilian city offers decreases of approximately 0.8 °C for the minimum temperature, 6.4 °C for the maximum, and 3.4 °C for the average.

In Mendoza, the impact of increase H/W aspect ratio on average and maximum temperatures in the urban canyon shows a positive effect in 2 of the 9 scenarios analyzed—E3.a and E6.a. The maximum temperatures lowered the averages by 3.5 and 1.4 °C. However, none of the minimum temperatures in any of the configured strategies for Mendoza showed thermal reduction during the cooling period. These research findings agree with the report by Erell et al. (2014), which shows stronger urban heat island (UHI) at noon in the summer for warm climate cities. The study also says that, although the maximum temperature decreases, the minimum temperatures increase.

Finally, our results show concrete possibilities for the reduction of energy consumption in both cities. In this sense, the International Energy Agency in the investigation "Technology Roadmap. Energy efficient building envelopes" (IEA 2009) affirms that the consequence of rehabilitating urban scenarios by reducing air temperatures by 2 °C would reverberate around the world and save 6 billion MJ in a projected study for 2050—the equivalent of the energy consumption of the UK.

5 Conclusions

When we analyze the efficiency of strategies according to the characteristics of the climate, all scenarios (18) displayed the same trends of heat mitigation; however, the magnitude of temperature decrease is greater in the case of the warm temperate climate (Campinas) than in the case of the desert climate (Mendoza). This emphasizes that uncontrollable variables in different warm climates—solar radiation, humidity, wind speed, cloudiness, etc.—determine the degree and intensity of the effect of each strategy, even when the urban morphology and materials are the same in both studied cities.

The result of this research also reveals the capabilities and advantages of working with ENVI-met software as a numeric simulation tool. The high degree of correlation in the measured daily curves of air temperature in each studied urban canyon, when compared with simulated curves, greatly supports the predictive results of urban thermal behavior during daytime and nighttime.

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