URBAN COOLING STRATEGIES APPLYING AT NEIGHBORHOOD SCALE FOR FACING HEATWAVE EVENTS

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ABSTRACT
Nowadays climate change is already affecting weather and climate extremes across the world, the scale of recent changes is unprecedented. Defined as prolonged periods of excessive heat, heatwaves are a specific type of extreme temperature event. Heatwaves are among the most dangerous of natural hazards. The study explored and analyzed how the implementation of heat-stress resilience strategies can create cooler settlements at neighborhood scale in arid contexts (Metropolitan Mendoza Area-Argentina). The methodology consists in an outdoor microclimate campaign and a computational model construction and statical validation for test outdoor cooling strategies (cool materials, street trees, densified, and the combination between them) in six scenarios. Results shows that combined strategies performance better, densified+cool materials+street trees, and cool materials+street trees. These scenarios can reduce temperatures for projected heatwave events by 3.8ºC in the maximum, 1.0ºC in the minimum and 2.1ºC in the average air temperatures; and 3.8ºC in the maximum, 0.8ºC in the minimum and 1.9ºC in the average air temperatures respectively. The main approach of the study is the evaluating of feasible strategies with the scope of generate neighborhood scale planning recommendations for cities with arid climates. Further studies would determinate which resilience strategy can be the most viable and cost-effective.

Key words: urban cooling strategies, neighborhood, heatwaves, computational simulation.

1. INTRODUCTION

Nowadays anthropogenic climate change is already affecting weather and climate extremes across the world, the scale of recent changes across the climate system, as well as the current state of many of its aspects, are unprecedented (IPCC, 2021). Current and future climate risks will not only be determined by changes in global temperature levels and associated hazards at the local scale, they will ultimately result from the combination of these hazards with the affected systems' exposure and vulnerability (ADAPTATION GAP REPORT, 2021). Climate risk is a function of exposure and vulnerability to climate hazards. A changing climate is expected to increase average summer temperatures and the frequency and intensity of hot days. In particular, the frequency and intensity of extreme temperatures is expected to change (PERKINS-KIRKPATRICK and LEWIS, 2020).

Defined as prolonged periods of excessive heat, heatwaves are a specific type of extreme temperature event (PERKINS and ALEXANDER, 2013). Heatwaves are among the most dangerous of natural hazards, but rarely receive adequate attention (NAIRN and FAWCETT, 2015). In contrast to other extreme climate events, heatwaves have only recently become recognized as a significant threat to environment and society (MÜLLER et al., 2021; BARROS et al., 2015). Financial losses from the 2009 heatwave in southeast Australia, for example, have been estimated at $800 million, mainly due to power outages and disruptions to the transport system (CHHETRI et al., 2012). This phenomenon in all countries could last at least ten times by 2050 (G20 CLIMATE RISK ATLAS, 2021). This event impacts directly into the living conditions in urban areas with higher temperatures due to the urban heat island (UHI) effect, and an intensified amplitude of urban overheating during heatwave events (CARVALHO et al., 2017). Older people and children's who live in cities that are not prepared for heatwaves or in areas with clear UHI effects have the highest risk of heat-related morbidity (RIKKERT et al., 2009).

The G20 Climate Risk Atlas shows key impacts on urban areas regard the heat stress from increasing frequency and intensity of heatwaves. Particularly for Argentina, observations show a general increase in the number of warm nights, alongside an increasing frequency of heatwaves in particular in the most recent period that affects major the urban centers. In the recent year, temperatures during the first 10 days of March were 8 to 10°C above normal in central Argentina, according to the country's National Meteorological Service. These temperature anomalies, which have persisted over huge areas, are unprecedented in climatic history at this scale.

The study area of this work, Metropolitan Mendoza Area (MMA), is the fourth city in demographic and economic importance in Argentina. It is located in the central west of the country with a high aridity index (low water availability, abundant solar resources throughout the year, high temperatures and thermal amplitude, and high percentage of clear days). On a microclimatic scale, the MMA register an UHI that reaches maximums of 10ºC and average values of 6ºC -values comparable with Tokyo, whose building density and intensity of anthropogenic contribution is visibly higher- (Correa, 2006). Besides, climate simulations estimated from atmosphere models shows important warming periods for the western region of Argentina (OLMO et al., 2020).

The built environment, limited to buildings and spaces between them, is the first element of population heat stress resilience as it can decrease exposure to heat (ZUO et al., 2014). Urban areas resiliency can be understood as the ongoing capacity of cities to absorb, adapt, transform and prepare for shocks and stresses along the economic, social, institutional and environmental dimensions, with the aim of maintaining the functions of a city and improving response to future shocks (FIGUEIREDO, HONIDEN and SCHUMANN, 2018). According to Schipper and Langston (2015) the three main approaches to resilience are the socio-ecological, the sustainable livelihoods, and the disaster risk reduction approaches. This study addresses two of these approaches: sustainable livelihoods and disaster risk reduction.

Regarding resilient cooling strategies ZHANG et al., (2021) performed a critical review on the state-of-the-art of, with special attention to their performance under heatwaves and power outages. They proposed a definition of resilient cooling and described four criteria for resilience —absorptive capacity, adaptive capacity, restorative capacity, and recovery speed—. They determinant that a single cooling strategy does not contain all the resilience capacities, and there may not be a universally optimal solution as certain cooling strategies might perform better in certain climates.

Within this background, the Urban Climate and Resiliency-Science Working Group, recommend that urgently undertake research related to understanding and translating the findings from research to applications that impact urban systems decisions and livability, especially in addressing future hazards (GONZALEZ et al., 2021). The vulnerabilities described require reducing temperatures in the urban areas, adapting to a new global scenario, and prepare for microclimatic uncertainty.

2. OBJECTIVE

The presented study seeks to increase the resiliency capacity of the MMA residential neighborhood`s by improve the outdoor thermal behavior during heatwave events. Through explore the result from the implementation of heat stress resilience strategies to create cooler settlements. The main goal is to evaluate which strategy results more efficient in order to create neighborhood scale planning recommendations for cities with arid climates.

3. METHOD

3.1. Study area selection process and description

To select a representative case within the MMA, the process was categorized into three urban levels: (i) district, (ii) neighborhood, and (iii) urban canyon. The MMA has six districts, namely, Mendoza Capital, Guaymallén, Las Heras, Godoy Cruz, Maipú, and Luján. The most populated districts are the three that borders the Capital; Guaymallén, Las Heras, and Godoy Cruz (INDEC, 2010). Within them Guaymallen results the most populated (283803 persons), this district has a territorial extension of 164km^2 with a population density of 1730.5 p/km^2. Between this district a graphic survey was conducted to classified and quantified, using AutoCAD software, the most representative urban block forms. Four different types were identified -square, rectangular E-W, rectangular N-S, and irregular-. The selection of these geometrical classifiers derives from the MMA urban regulation policies (Regulatory law n°4341/1978). The results of the survey show that 48% of the blocks in Guaymallén are considered irregular. Finally, for microclimate monitoring process, one urban canyon was considered as representative and selected according to a characterization process that used a set of six indicators and descriptors. The most predominant urban canyon was selected due to its representative conditions. A Cul-de-Sac grid neighborhood was selected -irregular blocks and streets with one inlet/outlet, oriented E-W-, forested with second magnitude street trees, 20 m streets widths, 3 m house heights, and albedos of 0.2, 0.3, and 0.5 for the roofs, façades, and streets, respectively, see Fig 1.

Figure 1. a) Guaymallen district, b) selected neighborhood, and c) monitored urban canyon.

3.2. Microclimatic data campaign

In order to assess the microclimatic behavior of the selected neighborhood a measuring campaign were made during January 8 to February 10, 2014. This year was particularly hot in the study area, anomalies were recorded in the average annual temperature (+0.5°C), with 2014 being fourth in the ranking of the 5 warmest years in Argentina (SMN, 2023).

A fixed data logger (HOBO UX100-003) was installed 2 m from the ground in a solar radiation shield to prevent irradiation and ensure adequate air circulation (Oke, 2004). The sensor was positioned at the center of the selected urban canyon cross-section, mounted to a wooden post on the North sidewalk. To evaluate how cooling strategies can improve the outdoor air temperature and the resiliency for heatwave events, a particular day with that condition was selected. By analyzing the climatic records extracted from wunderground (https://www.wunderground.com/history), high maximum air temperatures were detected during three consecutive days in the Mendoza airport meteorological station (number 87498): 01/15/2014

38ºC, 01/16/2014 40ºC and 01/17/2014 39ºC. Data show that January 16 results the hottest and overcome the barrier of 40ºC in the MMA. This day was selected as the study day to prove the performance of the outdoor cooling strategies.

3.3. Cooling strategies applying in outdoor spaces

In order to improve the outdoor thermal behavior of the neighborhood during heatwave events, six scenarios were tested taking into account the review of resilient cooling strategies by Zhang et al., (2021): (i) absorptive capacity, i e. cool materials (0.7 albedo's for horizontal surfaces and 0.5 albedo's for vertical surfaces, this values are recommended for the MMA by Alchapar and Correa, 2015); (ii) absorptive capacity, i e. street trees with regular implantation and homogeneous specie (*Morus alba* tree implanted by 6 m) in all the streets and in the central space of the neighborhood; (iii) absorptive capacity strategy combination (cool materials + street trees); (iv) absorptive, restorative and recovery speed capacity, i.e. increases the thermal mass by increasing buildings height to 9 m in the four central blocks (in the densified process the relationship between open and built areas inside each block was kept homogeneous in order to avoid any other variable in the thermal behavior contrast process, only the distribution of the building footprint were change, i e. N-S building ribbons); (v) absorptive, restorative and recovery speed capacity combination -densified scenario with the street trees-; (vi) absorptive, restorative and recovery speed capacity combination -densified scenario with cool materials and street trees-.

3.4. Scenario's configuration and ENVI-met simulation

ENVI-met software was used for this study. This tool is a 3D gridbased CFD tool for simulating surface-plant-air interactions using the fundamental laws of fluid dynamics and thermodynamics. ENVI-met requires two main input files: (i) area input file, that specify the geometry of model environment such as position and height of buildings, plants, distribution of surface materials and soil types in detail, also the geographic position of the location on earth, and (ii) configuration file, that defines the settings for the simulation to run, for example the name for the area input file, the name of the output files or the meteorological settings.

The six scenarios for the study -cool materials, street trees, cool materials + street trees, densified, densified + street trees, and densified + cool materials + street trees- were modeled within a horizontal area of 450 x 450 m that comprised a simulation version of 90 x 90 x 30, with cell grids of 5 x 5 x 3 m (x, y and z respectively). A total of five receptors were used in each model: four were positioned along the urban canyons and the other one was located in the center of the neighborhood; Fig. 2 show the ENVI-met model layout and the position of each receptor.

Figure 2. Receptor position.

The accuracy of the ENVI-met model was assessed by comparing the series of January 16, 2014 air temperature measurements with the corresponding simulated values. Also, the SVF values considered the adjustment of real case study values and those generated by the ENVI-met model (measured SVF 0.530 – adjusted SVF 0.602). Also, the model was statistically evaluated using a set of recommended indices that describe the magnitude of the difference between the observation and prediction, the indices and results are: R^2 0.92, RMSE 1.70, RSMEs 0.80, RSMEu 0.20, MAE 0.70, MBE 0.30. Based on statistical index values that were accepted in previous ENVI-met evaluation studies, the models can reliably simulate microclimate (TSOKA et al., 2017). Figure 3 show the thermal behavior for the heatwave day, the CFD adjusted day, and a representative summer day (01/14/2014) that was takes as a study day in previous works (SOSA et al., 2018; SOSA et al., 2017).

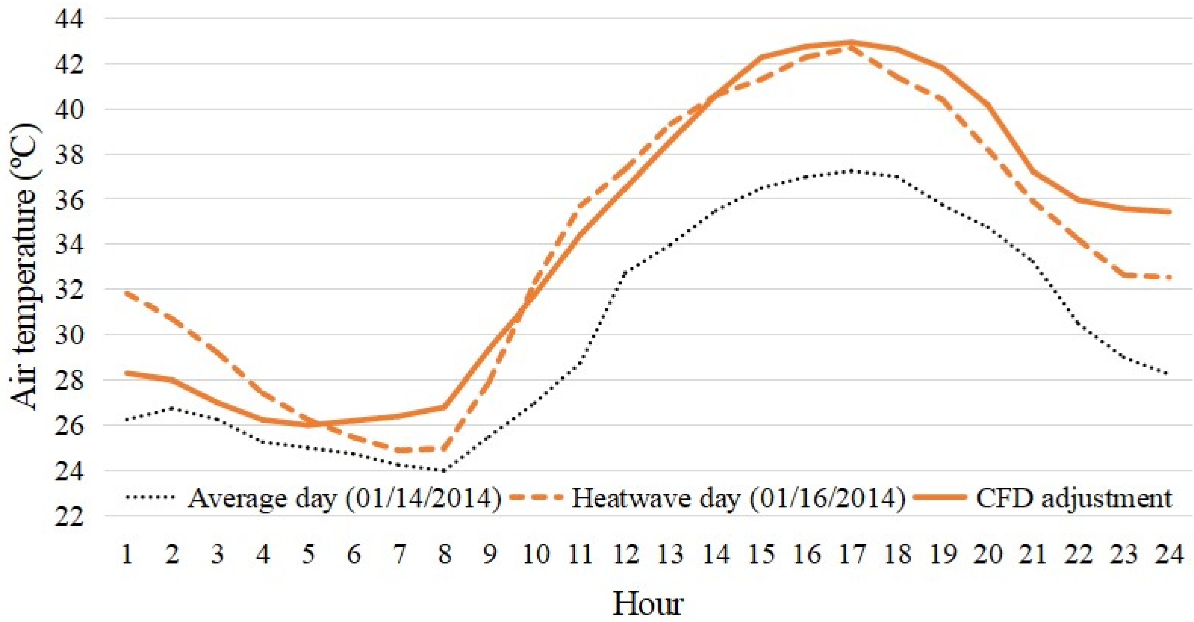


Figure 3. Thermal behavior of the selected heatwave day, the CFD adjustment, and the average day.

4. RESULTS

The outdoor cooling strategies performance of the six scenarios are shown in Fig. 4.

By analyzing the scenarios behavior, we can notice that all of them could help to improve the outdoor air temperature in contrast to the adjusted study day (heatwave day 01/16/2014: maximum 43ºC, minimum 26.0ºC, average 34.6ºC). The coolest scenario is the one that combines the three strategies: street trees + cool materials + densified (maximum 39.2ºC, minimum 25.0ºC, average 32.1ºC). The hottest is the one that was only densified (maximum 42.3ºC, minimum 25.9ºC, average 34.2ºC). Between the best and the worst scenarios there exist thermal differences of 3.1ºC in the maximum, 0.9ºC in the minimum, and 2.1ºC in the average air temperatures.

In terms of analyses each strategy individual performance we can notice that: (i) increase the thermal mass by increase the neighborhood density represent the worst outdoor cooling strategy (maximum 42.3ºC, minimum 25.9ºC, average 34.2ºC); (ii) apply only the cool materials strategy to horizontal and vertical surfaces is not so efficient (maximum 41.8ºC, minimum 26.2ºC, average 34.1ºC), the highest minimum air temperature were detected in the receptor 4 of this scenario (26.8ºC); (iii) increase the number of street trees, and forestry into the neighborhood central open space is the best option for decrease the maximum and minimum outdoor air temperatures (maximum 40.0ºC, minimum 25.2ºC, average 32.6ºC);

In terms of analyses the combination of strategies performances, we can detect that always the thermal behavior is improved: (i) the combination of cool materials + street trees (maximum 39.2ºC, minimum 25.2ºC, average 32.3ºC) in contrast to the heatwave adjusted day (maximum 43.0ºC, minimum 26.0ºC, average 34.2ºC) improves the outdoor air temperature by 3.8ºC in the maximum, 0.8ºC in the minimum and 1.9ºC in the average air temperatures; (ii) the combination of densified + street trees (maximum 39.8ºC, minimum 25.0ºC, average 32.3ºC) in contrast to the heatwave adjusted day (maximum 43.0ºC, minimum 26.0ºC, average 34.2ºC) improves the outdoor air temperature by 3.2ºC in the maximum, 1.0ºC in the minimum and 1.9ºC in the average air temperatures; (iii) the combination of the three strategies densified + street trees + cool materials (maximum 39.2ºC, minimum 25.0ºC, average 32.1ºC) in contrast to the heatwave adjusted day (maximum 43.0ºC, minimum 26.0ºC, average 34.2ºC) improves the outdoor air temperature by 3.8ºC in the maximum, 1.0ºC in the minimum and 2.1ºC in the average air temperatures. Also, in this scenario the receptor 2 achieves the lowest air temperatures (maximum 38.6ºC, minimum 24.3ºC, average 31.5ºC).

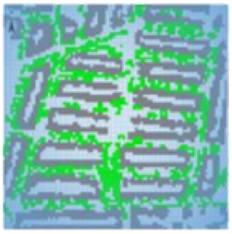
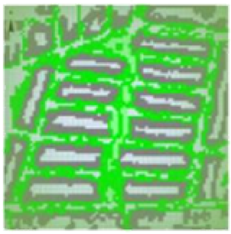
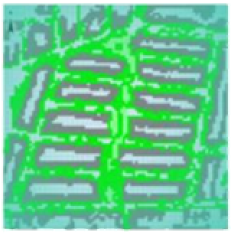
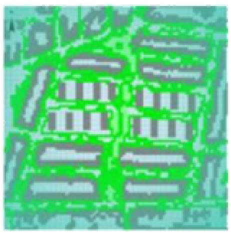
Strategy	Receptor	T. Max. (ºC)	T. Min. (ºC)	T. Ave. (ºC)
	1	41.5	26.6	34.1
	2	41.5	26.1	33.8
	3	41.6	25.7	33.7
	4	42.0	26.8	34.5
	5	42.3	25.8	34.4
Cool materials	All	**41.8**	**26.2**	**34.1**
	1	39.8	25.7	32.7
	2	39.6	25.0	32.2
	3	39.8	24.9	32.3
	4	40.0	25.5	32.6
	5	40.8	25.3	33.0
Street trees	All	**40.0**	**25.2**	**32.6**
	1	38.9	25.7	32.3
	2	38.8	25.0	31.9
	3	39.0	24.9	32.0
	4	39.2	25.5	32.3
	5	40.4	25.3	32.8
Cool materials + Street trees	All	**39.2**	**25.2**	**32.3**
	1	42.2	26.0	34.1
	2	42.0	25.4	33.7
	3	42.1	25.7	33.9
	4	42.5	26.6	34.7
	5	42.6	25.7	34.5
Densified	All	**42.3**	**25.9**	**34.2**
	1	39.5	25.3	32.4
	2	39.1	24.3	31.7
	3	39.8	24.8	32.2
	4	39.9	25.3	32.5
	5	40.7	25.1	32.8
Densified + Street trees	All	**39.8**	**25.0**	**32.3**
	1	39.0	25.3	32.1
	2	38.6	24.3	31.5
	3	39.0	24.8	31.9
	4	39.3	25.3	32.3
	5	40.5	25.1	32.7
Densified + Street trees + Cool materials	All	**39.2**	**25.0**	**32.1**
No cooling strategy	-	**43.0**	**26.0**	**34.2**

Figure 4. Outdoor thermal behavior of the six scenarios.

4.1. Outdoor cooling strategies efficiency ranking

Regarding the results we can categorize the scenarios from the most effective to the less effective, Fig. 5 summarize and difference the results in a ranking order differentiation maximum, minimum and average air temperatures.

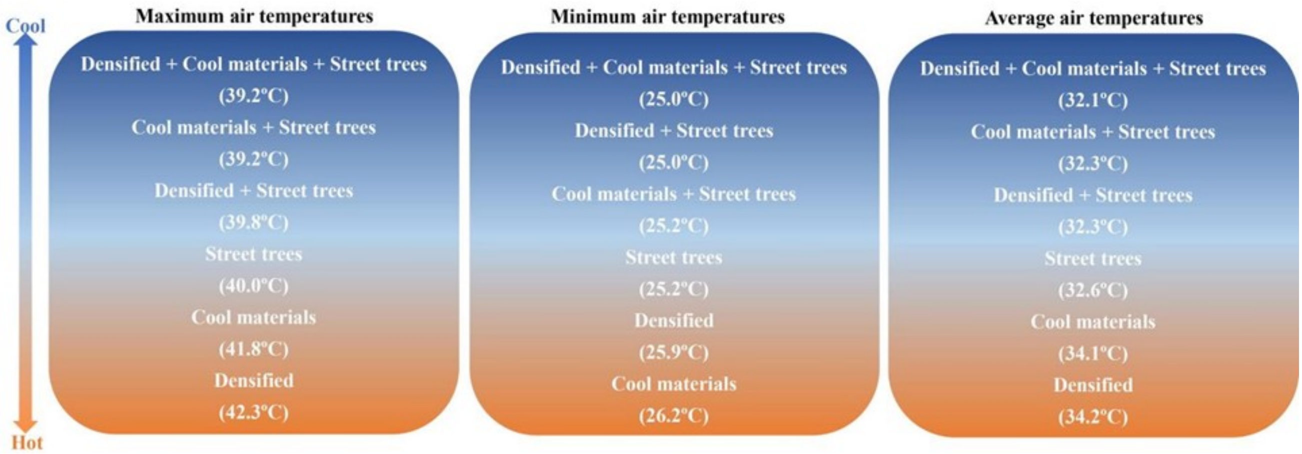


Figure 5. Cooling strategies ranking order.

By analyzing Fig. 5 it is detected that the combination between two or three outdoor cooling strategies achieve better results, than the strategy by itself. This seems to be a trending performance taking into account the findings in previous studies, were the combination of cooling strategies turns more efficient (SOSA et al., 2020; SOSA et al., 2018; KLEEREKOPER et al., 2012). Another finding we can notice by analyzing the diurnal (maximum air temperature) and nocturnal (minimum air temperature) thermal behaviors is that there are differences between the ranking order, i.e., between the second, third, fifth, and sixth cooling strategy order. The results show that by implemented the three strategies together the neighborhood´s air temperature will performance better during the day and nighttime. This would help to reduce the urban warming effect. The rest of possibilities assessed showed different levels of efficiency depending the hour.

5. CONCLUSIONS

The study explored and analyzed how the implementation of heat stress resilience strategies can create cooler settlements at neighborhood scale in arid contexts. Between the six tested scenarios -cool materials, street trees, cool materials + street trees, densified, densified + street trees, and densified + cool materials + street trees- planning recommendations for cities with arid climates are given. The best scenarios in the cooling ranking are the two that combines strategies, i. e. densified + cool materials + street trees, and cool materials + street trees. These scenarios can reduce the outdoor air temperatures for projected heatwave events by 3.8ºC in the maximum, 1.0ºC in the minimum and 2.1ºC in the average air temperatures; and 3.8ºC in the maximum, 0.8ºC in the minimum and 1.9ºC in the average air temperatures respectively. On the other hand, by implementing a unique cooling strategy the increment the number of street trees results more efficient than applied cool materials to the exposed surfaces, between these two strategies the air temperatures differences reach 1.8ºC in the maximum, 1.0ºC in the minimum and 1.5ºC in the average. Another finding shows that only increase the thermal mass by densified is the worst outdoor cooling strategy; this fact is preoccupying since the MMA is actually facing a non-so planning densification process in consolidated areas that could exacerbated the air temperatures in heatwave days. The main approach of the study was the outdoor thermal behavior quantification by the implementation of feasible cooling strategies for a real context during heatwaves hazards. Further studies would be carried out to assess recent temperatures and heat wave events in order determinate which resilience strategy can be the most viable and cost-effective approach for mitigating urban extreme temperatures in arid contexts.

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