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Evaluating the microclimatic performance of nature-based solution combinations

A multi-scenario simulation study in the mediterranean coastal city of Valparaíso, Chile

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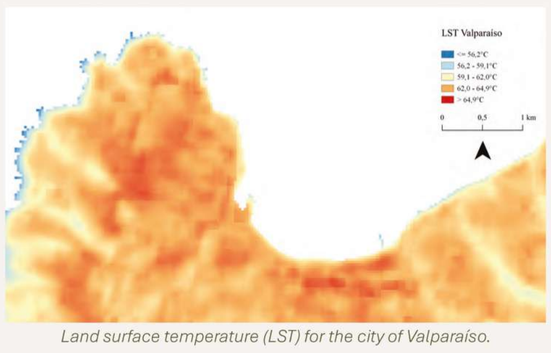
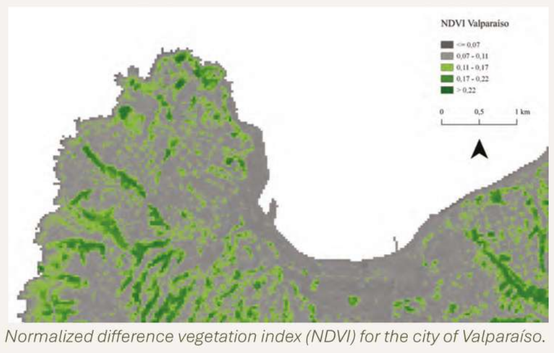
Urban challenge

The Urban Heat Island (UHI) effects intensify thermal stress in dense urban environments, increasing energy demand and affecting outdoor thermal comfort and public health. These challenges are particularly complex in historic districts, where climate adaptation strategies must operate within strict heritage conservation frameworks.

This research evaluates the microclimatic performance of different combinations of nature-based solutions (NbS) in the historic neighbourhood of "El Almendral", Valparaíso, Chile.



Land surface temperature (LST) for the city of Valparaíso.



Normalized difference vegetation index (NDVI) for the city of Valparaíso.

Study area

The study focuses on "El Almendral", a historic neighborhood of Valparaíso located in a Mediterranean coastal climate zone. The area is characterized by a dense urban morphology, limited urban vegetation, and a high proportion of impervious surfaces. In addition, heritage conservation regulations impose restrictions on urban interventions within the built environment. Together, these conditions create a particularly challenging context for the implementation of climate adaptation strategies.

Map of the study area within the historic neighborhood "El Almendral" in the coastal city of Valparaíso

Methodology

The research combines urban analysis with microclimatic simulation to evaluate the impact of different intervention strategies. The methodological framework consists of three stages:

1. **Urban assessment** — Historical, urban, and environmental analysis of the study area.
2. **Scenario simulation** — Development and calibration of an ENVI-met model.
3. **Comparative analysis** — Evaluation of microclimatic performance across multiple intervention scenarios.

Scenarios design

Image of the soil and surface configuration in the ENVI-met model for the base case.

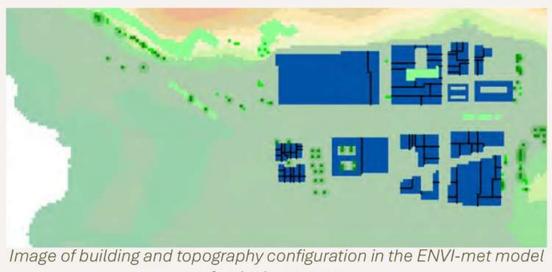


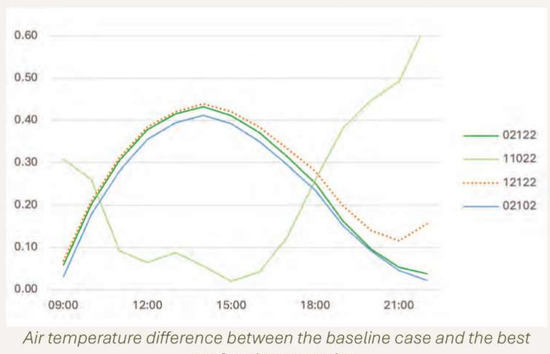
Image of building and topography configuration in the ENVI-met model for the base case.

A total of 20 simulation scenarios were generated through systematic combinations of five design variables, of a universe of 183 posible scenarios. These variables were combined to explore different nature-based solution configurations and their influence on urban microclimatic conditions.

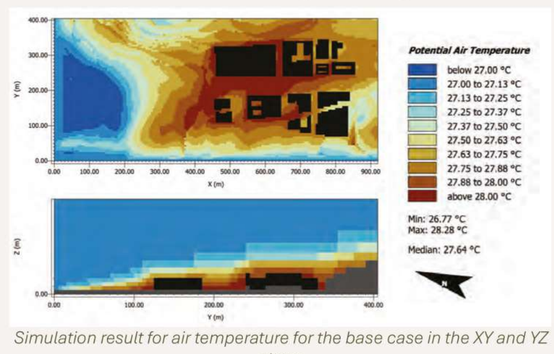
Value	Green façade	Vegetation	Water	Albedo	Window- wall
0	No	No	No	Original	50%
1	Lightweight	Low	Natural	Black	100% window
2	Robust	High	Artificial	White	100% wall

Results

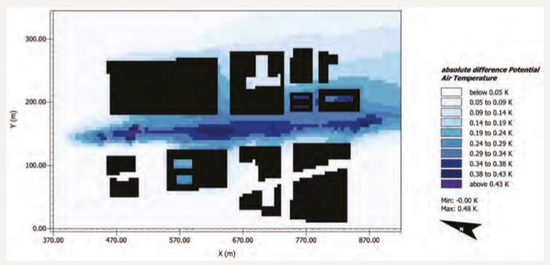
The simulations reveal significant differences in the cooling performance of the evaluated scenarios. When ranked according to cumulative temperature reduction during the simulation period, the best-performing configurations was scenario 12122 showing the highest overall temperature reduction. These results highlight the importance of integrating multiple nature-based strategies to enhance urban cooling performance. In terms of peak cooling performance, scenario 11022 produced the highest maximum temperature reduction, indicating that certain configurations may generate stronger localized cooling effects.



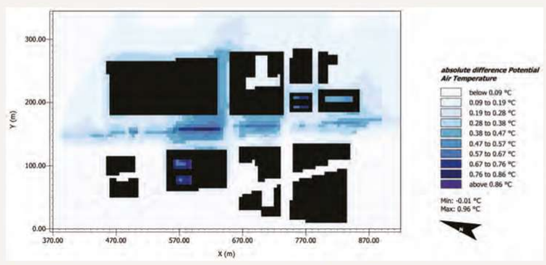
Air temperature difference between the baseline case and the best performing scenarios.



Simulation result for air temperature for the base case in the XY and YZ plane.



Results of the comparison of air temperature between scenario 12122 and the base case at the time of greatest impact (14:00).



Results of the comparison of air temperature between scenario 11022 and the base case at the time of greatest impact (22:00).

Code	Cumulative difference [°C]	Max[°C]	Min[°C]	Average [°C]
12122	3.861	0.439	0.068	0.276
02122	3.487	0.432	0.038	0.249
11022	3.269	0.632	0.020	0.234
02102	3.233	0.412	0.022	0.231

Conclusions

- Vegetation-based strategies produce the strongest cooling effects.
- Scenarios combining multiple nature-based solutions consistently outperform single-variable interventions.
- Green façade systems enhance the effectiveness of vegetation-based strategies in dense urban contexts.
- Water interventions show moderate performance, likely influenced by the already high humidity levels typical of coastal Mediterranean climates.

Acknowledgments

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