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Mitigation strategies of the urban heat island intensity in Mediterranean climates: simulation studies in Rome (Italy) and Valparaiso (Chile)

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Mitigation strategies of the urban heat island intensity in Mediterranean climates: simulation studies in Rome (Italy) and Valparaiso (Chile).

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Abstract. The Urbanocene, a proposed new geological epoch characterized by the urban living condition, is pressing the humanity to respond shortly to important challenges. Cities are at the same time the places where we live in and the big dissipators of the final energy to the environment. The simultaneous rules of heat dissipator and place to live are quite contradictory, because of the increasing temperatures of the dissipator surfaces, phenomenon known as Urban Heat Island (UHI). Mediterranean climates should suffer, in the next years, changes in the thermal needs of buildings and in the outdoor comfort sensations. A change in the energy demand from heating to cooling is probable and overheating reduction could be a priority in the future. Many mitigation strategies of UHI are being discussed in these years, such as the city greening, the use of cool materials for roofs and soils, the reduction of automobile dependence, the shift to new urban morphologies. In this paper an evaluation of impacts of different possible strategies is done, by using computational simulations for various sectors of Rome and Valparaiso. Results show the importance of greening and traffic reduction to achieve better comfort; while to reduce building energy consumption changes in urban morphology and traffic are suggested as the best strategies.

1. Introduction

The domain of our specie on the planet has been continuously rising since we appear on the Earth. Today, the concept of Anthropocene is being proposed as a new geological epoch (and even as a new stratigraphic epoch [1]). Besides geological discussion on the appropriateness of the concept, one of the characteristics of the last 1.000 years has been the urban condition of the humans, and this condition is growing so fast since the “great acceleration” times that some scientist propose the name “Urbanocene” as an alternative to “Anthropocene” [2]. One of the specific aspects of living in cities is that such adaptive complex system has the behavior of a dissipative structure [3]. So, cities are the places where most of the humans live; the places where most of the final energy is consumed; and the most important: the places where the heat that results by all these energy transformations is dissipated to the environment. The phenomenon is known as Urban Heat Island and has been investigated since the 19th Century, but it was formalized under an energetic point of view recently at the end of the 20th Century [4-5]. Recent studies underlined the possible impact of UHI on the cooling needs of buildings



[6-7] and on the summer outdoor comfort [8]. Even the interrelationship between extreme events (heat waves) and UHI has been assessed [9]. Advancing in urban climate studies, many models and methodologies to estimate temperature and other environmental parameters variations in urban conditions have been developed [10]. Specifically focusing on UHI, one of the validated tools that is being used to generate weather files is the Urban Weather Generator [11]. This tool couples an atmospheric model with a building simulation model to generate a weather file useful to conduct building energy simulation considering the UHI effect.

2. Methodology

In this paper the Urban Weather Generator tool is used to obtain urban weather data to be used in comfort and building energy simulations. Four cases of study are explored, two in the city of Rome, Italy and two in Valparaiso, Chile. Comfort evaluations have been done using PMV calculator [12], while building energy simulations have been carried out using the TRNSYS tool (version17). Then, three possible mitigation strategies (greening the cities, reducing traffic, and changing pavements and roofs materials) have been tested to obtain the improvement in outdoor comfort and the reduction of cooling needs generated by each and combining all.

2.1. Cases of study

Rome (lat. 41.54 N, long. 12.29 E) and Valparaiso (lat. 33.02 S, long. 71.36 O) are both placed in Mediterranean climatic context, with dry hot summer and cold wet winter. Koppen climate classification for both cities is Csa (a climate that is present in the Mediterranean area, in Chile, in California and in some parts of Australia and South Africa). Such climates present some sensitivities to climate change and to urban heat island phenomenon [13]. Cities' morphologies are different: Valparaiso is smaller than Rome and it is placed on the coast, while Rome locates about 20 km far from the Sea. Mediterranean Sea and Pacific Ocean have also a very different impact on urban microclimate: the Humboldt Current is cooling both air and water of the Chilean coast much more than the Mediterranean Sea currents could do in the case of the coast close to Rome. Orography presents some similarities: both cities have many small mountains that obviously influenced the urban planning. In Rome two sectors have been selected for this analysis, one corresponding to the center of the city (Tridente) and other corresponding to a residential neighbor close to the center (Prati). In Valparaiso, the selected sectors are the city center (Center), with its system of places, and a residential neighbor sparsely built (Recreo). Figures 1 and 2 shows both cities and their sectors selected for analysis.

2.2. Urban weather and building energy simulation

Urban Weather Generator is a tool developed at MIT. The tool couples an atmospheric model and a building performance simulator to obtain modified urban weather files from a base rural weather file. Many information is needed by the tool to conduct simulations, however some of the most sensitive parameters are: the anthropogenic heat production, the morphology parameters (built up area, façade ratio, average building height, green areas) and the material properties (albedo and emissivity) of streets, walls and roofs [14-15]. Table 2 resumes the parameters used in UWG simulations for the four cases. Building energy simulations have been carried out using the TRNSYS tool (version17). A five stories building is used as test building, E-W oriented, with windows representing a 27% of the main façades. Each story is divided in four apartments of 50 m². Table 1 resumes parameters used in BES.

Table 1: Building Simulation Parameters

U wall (W/m ² K)	U roof (W/m ² K)	U floor (W/m ² K)	Infiltration (h ⁻¹)	Glazed surface main façade (%)	Occupancy (people)	Gains (W7m ²)	Cooling set point (°C)
2.15	0.57	1.88	0.7	27	2	5	26



Figure 1. The city of Rome and its neighbours “Prati” and “Tridente”.



Figure 2. The city of Valparaiso and its neighbours “Center” and “Recreo”.

Table 2: UWG Simulation Parameters

	Rome Tridente	Rome Prati	Valparaiso Center	Valparaiso Recreo
Reference site				
Latitude (°)	41.54		33.02	
Longitude (°)	12.29		71.36	
Urban Area				
Site coverage (-)	0.7	0.49	0.49	0.62
Façade ratio (-)	1.96	1.43	1.24	1.48
Average height (m)	16.5	19.5	14.4	8.36
Tree coverage (-)	0.03	0.05	0.01	0.05
Vegetation coverage (-)	0.04	0.1	0.02	0.1
Anthropogenic heat (W/m ²)	25			
Materials				
Wall materials and thickness	Bricks 43 cm			
Roof materials and thickness	Insulated 38 cm			
Roof albedo (-)	0.25			
Road albedo (-)	0.2			
Rural				
Albedo (-)	0.2			
Emissivity (-)	0.95			
Vegetation coverage (%)	48			

2.3. Outdoor comfort evaluation

Comfort evaluations have been done using PMV method initially proposed by Fanger and then developed by many authors. Please notice that actually PMV is not the most appropriated method to assess outdoor comfort, as noticed by many authors that proposed alternative adaptive evaluations [16-17]. However, the obtention of a value for the body stress generated by gains or losses of heat, is correct in both indoor and outdoor conditions. It is only the thermal sensation vote that changes, influenced by psychological expectations, culture and adaptation. We take PMV results just as indicative of a theoretical situation that in reality could be felt as a little more comfortable because of adaptation. The estimations have been done without considering short wave radiation, this means, always on shadow. The variables considered are: metabolism, clothing, air temperature, relative humidity, wind velocity and mean radiant temperature. MRT was assessed as the average weighted by view factors of surfaces temperatures of the urban environment (walls and pavements). View factors are representative of a person placed close to one of the building walls on shadow.

2.4. Improvements

Considered possible improvements that should be done in order to build adaptive capacity and mitigate urban heat island are:

- Increasing the green areas of neighbours in a 100% respect to actuality
- Changing the materials of pavements and roofs for selective cool materials
- Reducing anthropogenic heat generation by cars in a 50%

To test the impact of each improvement on thermal comfort and cooling needs in summer period, a new set of UWG simulations is done, changing the respective parameters. In the case of city greening the “vegetation coverage” and the “trees coverage” parameter are changed UWG. In the case of the pavements and roofs, “albedo” parameters for urban streets are changed in UWG and “albedo” parameters for roof are changed in TRNSYS. In the case of anthropogenic heat, “sensible heat” is changed in UWG.

3. Results and discussion

3.1. Comfort

Table 3 resumes the environmental parameters (air velocity, relative humidity, air temperature and mean radiant temperature) used in the PMV evaluation for the case of Rome. Metabolic activity was set to 2 met (116 W/m^2) and the mechanic efficiency of the human body is considered 50%. Respect to clothing, thermal resistance of the clothes is set to 0.5 Clo and the clothes factor is set to 1.15. As stated in the methodology section, the evaluation is done without consider direct radiation from the Sun. Wind velocity value was approximated to 0.5 m/s for the rural case and 0.2 m/s for the urban.

Table 3: PMV parameters, Rome

	Rural Rome	Prati	Tridente	Prati green	Tridente green	Prati 50% traffic	Tridente 50% traffic	Prati cool pavement	Tridente cool pavement	Prati combined	Tridente combined
V (m/s)	0.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Hr (%)	45	40	38	41	40	40	38	40	40	41	40
T (°C)	28	30	31	29.5	29.8	29.9	30.9	30	31	29.3	30.8
T _{mr} (°C)	30	32	33	28	29.5	29.9	32.9	31	32	27	28.3

Figure 3 shows the results in terms of PMV and PPD. It can be observed that the rural outdoor comfort evaluation leads to an acceptable situation, very close to thermal neutrality and with a PPD of 5%. Urban conditions are worse, with a PMV value close to 1 (slightly warm) and a PPD of 20-25% depending on specific urban environment. Proposed improvements combined permits to reach an intermediate situation (PMV 0.6-0.7 and PPD 11-15%). The best improvement is obtained by increase the green (trees) surface of a 100%.

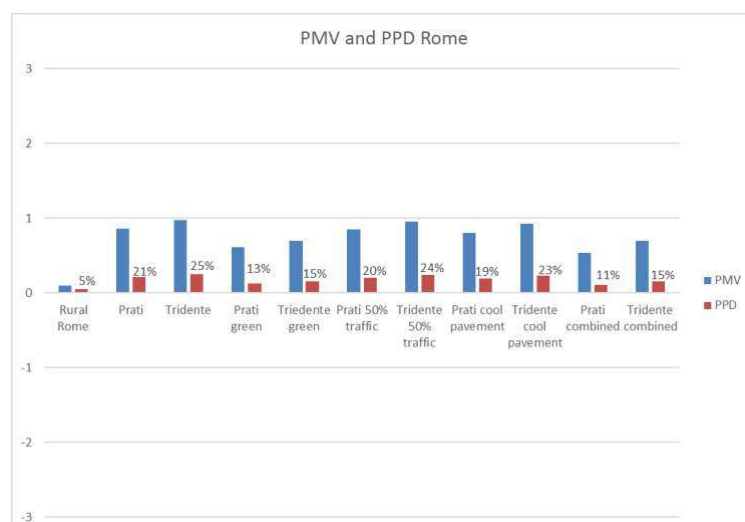


Figure 3: PMV and PPD, Rome

Table 4 resumes the same parameter for Valparaíso. The same metabolism and clothing of the Rome case are used. Because of the city emplacement, on the Pacific Ocean, air speed is considered 1 m/s in the rural case and 0.5 m/s in the urban configurations.

Table 4: PMV parameters, Valparaíso

	Rural Valparaíso	Centre	Recreo	Centre green	Recreo green	Centre 50% traffic	Recreo 50% traffic	Centre cool pavement	Recreo cool pavement	Centre combined	Recreo combined
V (m/s)	1	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Hr (%)	30	28	28	29	29	28	28	28	28	29	29
T (°C)	33	34	33.5	33.5	33	33.9	33.4	34	33.5	33.3	32.8
T _{mr} (°C)	34	37	35.5	35	30	36	32	36	34.5	34	29

Figure 4 shows the PMV and PPD values obtained. Comfort situation seems to be a little more difficult to be reached in this case. However, the green improvement is again the best strategy between tested improvements.

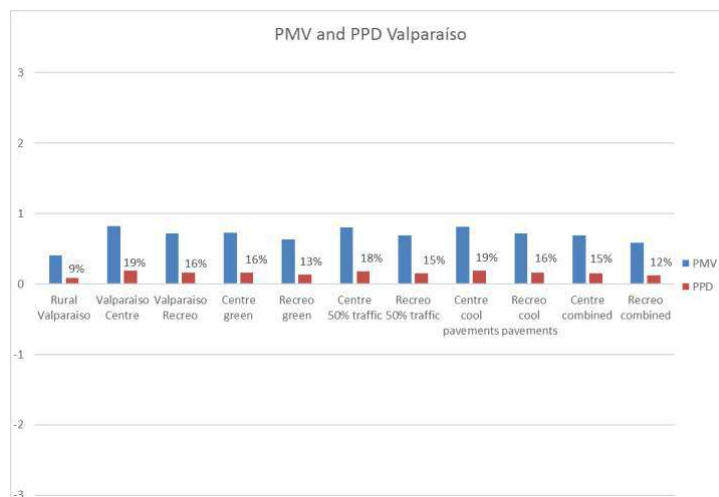


Figure 4: PMV and PPD, Valparaíso

3.2. Cooling needs

Figures 5 and 6 show the cooling needs across the year for Rome and Valparaíso. It can be observed that if Valparaíso has maximum values of temperature higher than Rome (as detected for the comfort analysis), this case has also lower temperatures during the nights, leading to a total cooling need quite lower than the case of Rome. The effect of city morphology (density and façades) is detected as the most important factor in the case of Rome. In Valparaíso, the increase in height of building of the Centre is counteracted by the reduction in density respect to Recreo case. Cool pavements and roofs are suggested as the best strategy to reduce cooling needs in both cases, but especially in Valparaíso.

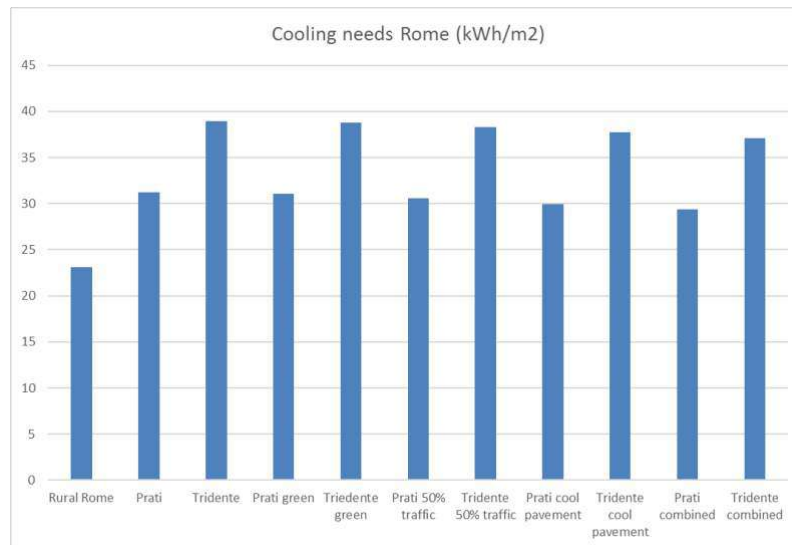


Figure 5: cooling needs, Rome

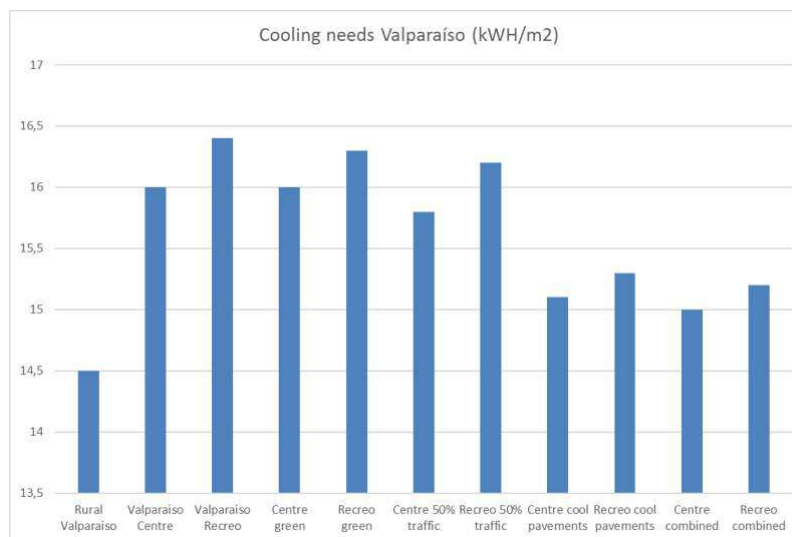


Figure 6: cooling needs, Valparaíso

4. Conclusion

This paper analyzed comfort and cooling implications of the urban environment in Mediterranean climates, by studying the cases of Rome, Italy and Valparaíso, Chile. Results show that the impact of urbanization is important both on outdoor comfort than on cooling needs. A set of mitigation strategies has been tested, suggesting that greening the city is the best strategy to improve outdoor habitability, while using cool selective materials on the pavements and (especially) roofs the total cooling need could be reduced up to the 40%. Research limitations suggest also that the effect of traffic reduction and city greening could be in reality more than detected in this study. If a more exhaustive comfort evaluation would be done, including direct Sun radiation, it is very probable that the use of trees should evidence an impact on psychological perceived temperature of more than the difference between “neutrality” and “slightly warm” detected by approximate PMV analysis. Respect to traffic,

this is a very local condition. The average impact on the urban area is clearly reduced. However, outdoor comfort close to a busy street would be probably influenced mainly by the quantity of cars present. Future studies should be addressed to these observations. Cooling analysis can also be improved. In this paper, only the UHI effect has been considered replacing the “base” weather file with a “urban” weather file generated by UWG. Recent studies [18-19] put in evidence that also shadows, infra-red environment and wind distribution changes have to be included in analysis. However, the impact of city morphology and materials is a fact that has been stated clearly [20]. In any case, further research on the calibration of BES including urban climate effects is needed

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