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Editorial

Introducing Urban Overheating—Progress on Mitigation Science and Engineering Applications

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1. Introduction

Buildings and construction is the most important economic sector in the world after agriculture. It represents a total turnover of 8.2 trillion dollars while forecasts for 2025 predict a total budget that is close to 15 trillion dollars [1]. In parallel, it offers employment to more than 110 million people around the world [2].

Despite the huge contribution of the construction sector in the global economy, it is actually facing very important challenges such as:

- Local and Global climate change that increases the energy consumption for cooling, increases the concentration of pollutants, deteriorates indoor and outdoor thermal comfort conditions and has a tremendous impact on heat-related mortality and morbidity [3], while it increases the ecological footprint of cities and urban settlements
- Overpopulation and economic growth in the developing world put a serious strain on the construction sector as some billions of new houses, building and infrastructures must be designed and built in the immediate next years
- The number of low-income individuals in both the developed and developing countries is increasing tremendously as the price of energy is rising, employment rates are decreasing and social equity seems not to be a high priority for modern societies. This puts billions of low-income people under threat and increases the health budget enormously.

The impact of local climate change on the energy consumption of buildings is now very well documented. Several studies have proven that because of urban overheating the cooling energy consumption of buildings may double [4,5], while the peak electricity demand may increase considerably and oblige utilities to build new power plants continuously to satisfy the additional demand [6]. In parallel, several recent studies have shown that heat-related mortality and morbidity has increased substantially when the ambient temperature increases during the summer period [7].

To face the problem of local and global climate change and to provide adequate housing to the vulnerable population, advanced mitigation and adaptation technologies have been proposed, developed and implemented all around the world successfully [8]. Mitigation technologies aim to fight the sources of overheating and counterbalance its impact, while adaptation technologies mainly aim to provide additional protection to the residents and the dwellers of the buildings.

Some of the most successful proposed mitigation technologies involve the use of reflective, cool, materials for buildings and urban structures, other advanced materials to decrease the urban temperature like thermochromic or radiative cooling structures, intensive use of greenery, use of water for evaporation, as well as other dissipation methods and technologies like the use of the ground [9].

In particular, the development of advanced materials for the outdoor built environment, like highly reflective light color materials, infrared reflective materials, thermochromic and fluorescent materials as well as photonic and plasmonic structures for radiative cooling contribute highly to decrease the peak ambient temperature up to 1.5–2.0 °C [10–13].

Advanced materials for mitigation as well as a combination of all the other mitigation technologies are implemented in hundreds of large scale urban rehabilitation projects. Monitoring and theoretical results show that it is possible to decrease the peak ambient temperature up to 3 °C. However, given the amplitude of the local overheating that exceeds 10 °C in many cases, there is a profound need to develop more efficient mitigation technologies able to provide a higher temperature reduction

2. Aim and Scope

The sim of the present special issue on "Urban Overheating—Progress on Mitigation Science and Engineering Applications" was to collect papers that are able to represent the newest information relating to the science, technology, application and policy perspective of urban environment overheating and its potential mitigation. Several hot topics were indicated for contribution:

- Studies and monitoring of urban overheating and mitigation technologies and strategies in real urban conditions;
- Modeling of the urban climate for an accurate assessment of mitigation solutions;
- Development of methodologies and tools to detect, predict and mitigate urban overheating;
- Implementation of policies and instruments to support the thermal rehabilitation of urban areas;
- Exemplary cases and demonstration projects.

These topics and also additional ones were deeply investigated in this paper's collection.

3. Presentation of the Published Papers

This Special Issue collects 18 relevant studies coming from 4 continents (South and North America, Asia, Europe, Oceania) and depicts this complex and multi-disciplinarily topic. The issues covered by the following contributions: four papers deal with urban overheating and urban heat island observation, with coupled methodological approaches; four papers deal with the outdoor microclimatic analysis and eventual mitigation strategies; three papers deal with the thermal interaction of buildings and the urban environment; three papers deal with the role and the impact of fabric materials in affecting the urban climates; two papers deal with urban greenery and mitigation; finally, one paper is about outdoor thermal comfort and one is about urban geometry. The incidence of each category, expressed in percentages, is reported in the following graph (Figure 1).

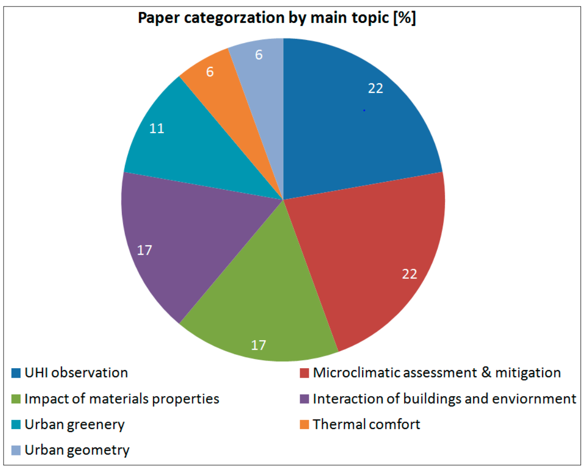

Figure 1. The paper categorization according to the main topic investigated.

3.1. Urban Overheating and Heat Island Observation and Analysis

A study aimed at identifying and quantifying an urban heat island index is presented in Reference [14]. The study is implemented at the census-tract level and intends to provide a reliable tool for health agencies to assess issues such as public overheating and air quality issues. By multi-scale modeling sorted by observation data, the index, based on several metrics, provides details of the urban heat island as a function of the urban seize area. The observation of the thermal environment, crucial to developing a mitigation plan, is carried out by high and medium spatial resolution satellite data from Reference [15]. The objective of this study is the implementation of a methodology that is able to identify "hot spots" and "cold spots" in a large metropolis such as Athens, and to quantify the thermal stress in the different zones of the city. Again the city of Athens is the field for a detailed analysis of urban climate in Reference [16], where the issue of understanding and manipulating big data coming from extensive environmental monitoring is carried out. In particular, a power spectral density analysis is performed over time scales spanning 10 min to several days, evidencing that air temperature data exhibit turbulent-like intermittent properties with multi-fractal statistics. Thermal datasets acquired for the city of Basel are used to validate a multiple linear regression model that is able to model the urban temperature distribution in a continuous way [17]. The model is based on the factors that mostly affect the urban heat island at night and the main outcome is that different datasets can be used to predict the heat island with comparable results.

3.2. The Role of the Materials in Urban Overheating Mitigation

It is well known that construction materials severely affect urban overheating because of their solar absorbing and heat storing properties. Increasing the albedo of cities is hence a major mitigation strategy. The impact of a relevant increase of albedo for roofs, facades and pavements is analyzed for Sacramento, Houston and Chicago in Reference [18], with the objective of estimating thermal mitigation, as well as air quality and human health. Starting from the measured datasets and combining chemistry and multi-layer canopy models, a decrease of ambient temperature up to 2.3 °C is calculated, as well as a decrease of PM2.5 and O_3 concentrations up to 2.7 $\mu g/m^3$ and 6.3 ppb. The role of materials, as well as of the canopy covers, is analyzed in research carried out in Los Angeles, which couples datasets acquired by shielded sensors mounted atop automobiles and WRF meteorological modeling [19]. It was found that the increase of albedo may lead to temperature reductions of up to 2.8 °C at the neighborhood scale. Higher albedo also means a higher luminous reflectance, which can provide an up to 75% reduction of electricity use for lighting, as proven in Reference [20]. In this paper, cool coatings for existing asphaltic surfaces are analyzed and, despite energy savings, it is evidenced that their optical behavior may affect the uniformity of visions for drivers and pedestrians, thus requiring ad-hoc installations.

3.3. The Role of the Green in Urban Overheating Mitigation

The role of greenery on urban mitigation is well explored and estimating the cooling potential is important when designing or rehabilitating green areas. Mobile measurements and computed fluid-dynamics analyses are carried out for a green area in the city of Kobe [21]. The numerical results, confirmed by monitoring, evidence that at a 30 m distance, the urban air temperature is not affected by the beneficial contribution of the green zone due to the sharp increase of the air temperature when entering the urban area. General information on the proper design of urban parks and areas are provided in Reference [22], where the cooling power is analyzed as a function of several variables relating to the physical parameters and characteristics of urban geometry. The analysis shows that the main parameter that can positively affect the urban climate in the surrounding area is the size of the park, with all the other parameters being less relevant.

3.4. The Interaction between Buildings and the Urban Environment

Buildings heavily affect urban overheating because of the characteristics of envelope materials and the ambient heat released because of active cooling and heating systems. The solar reflectance index, which takes into account the solar reflectance and thermal emittance of building materials, can be used to predict the thermal behavior of a surface subjected to solar irradiation. The correlation of the index with the heat released to the environment, as well as a sensitivity analysis of different input parameters, is analyzed in Reference [23]. While most studies focus on roofs, a lack of data exists for vertical walls and facades, which play a crucial role in the heat exchange between fabrics and ambient air under the canopy. A novel application of the empirical line method to calibrate a terrestrial low-cost multispectral sensor to recover spectral reflectance is developed in Reference [24]; promising results are achieved for this technique, able to characterize the building facades on site. The impact of buildings on energy uses is well recognized worldwide, an optimized procedure for cost optima renovation is carried out in Reference [25]. From among the results, the reduction of close to 30% of equivalent CO_2 emissions has to be mentioned, resulting in laying the groundwork for favorable conditions for urban climate mitigation.

3.5. Microclimatic Assessment and Mitigation

Microclimatic monitoring and calculation analyses help to understand the thermal response in specific areas that may be used to generalize the results at the city level, thus being important for policymakers. An accurate analysis of Athens is carried out in Reference [26], where urban temperatures were monitored in different zones of the city. The results showed the daily air temperature differences in the 5–8 °C range between the hottest and the coolest zones; the results also showed the dependence of local overheating as a function of climatic, geometrical and thermo-physical variables. Similar analyses are carried out for the city of Wien in Reference [27]. In this case, the numerical analysis followed-up the monitoring to verify the effectiveness of the selected mitigation strategies. Particular attention was given to tree planting, resulting in it being more efficient than green roof for urban mitigation and overheating prevention in buildings, thanks to the provided solar protection of windows. Additionally, in Rome, the monitoring and impact of mitigation technologies are carried out with a clear focus on architectural integration from the perspective of a holistic rehabilitation of a school campus [28]. Results take into account temperature mitigation, but also demonstrate the improvement of thermal comfort conditions using the Physiologically Equivalent Temperature as the driving indicator. The last paper on this topic, being the study focused on the rehabilitation of small public areas of the city of Beirut, couples numerical analyses of mitigation strategies with a strong policy analysis [29]. The results here show limited mitigation potential due to the size of the zones, but provide insights on the way municipalities may implement regenerative actions on the urban territory with a focus on sustainable issues.

3.6. Other Topics

The debated issue about the concordance between the outdoor thermal comfort indexes and the thermal sensation of users collected through questionnaires is the topic addressed in Reference [30]. The two methods are applied in Santa Maria, Brazil, and, thanks to a linear regression model, the results prove that there is a significant improvement in the agreement between instrumental assessment and subjective response to thermal comfort. The role of solar irradiation is crucial for the latter issue and it has a strong relationship to urban geometry. The last paper explores this aspect, analyzing and comparing two methods for assessing the sky view factor in densely built urban environments and identifying optimized calculation processes. The study is applied to calculate the sky view factor of each building block of Paris [31].

4. Conclusions

The papers included in this special issues show the complexity and multidisciplinary of the investigated topic, namely the urban overheating and its mitigation and adaptation. The presented body of work evidences the magnitude of the phenomenon, as well as potentials and limits of observation and detection instruments, and of the mitigation technologies and strategies. It also causes the role of the design and of policy instruments for the rehabilitation of thermally deteriorated urban areas to emerge.

Continuous efforts are needed in the future to properly address several open issues: methods and tools to accurately estimated urban overheating as a function of multiple variables affecting the phenomenon; innovative technologies and strategies to mitigate overheating in built urban environments (materials, green and blue technologies); accurate modeling of the urban environment with focus on fluid and thermodynamic aspects; and applications with a clear demonstration of the mitigation solutions in practice. Overheating and mitigation of the urban environment is, hence, a topic that will deserve attention and research activities in the next few years when its impact will be amplified by the consequence of climate change and global warming.

References

1. Santamouris, M. Innovating to zero the building sector in Europe: Minimising the energy consumption, eradication of the energy poverty and mitigating the local climate change. *Sol. Energy* **2016**, *128*, 61–94. [CrossRef]
2. WIEGO. Woman in Informal Economy: Globalizing and Organising: Construction Workers. 2015. Available online: http://wiego.org/informal-economy/occupational-groups/construction-workers (accessed on 12 January 2018).
3. Santamouris, M.; Kolokotsa, D. On the Impact of Urban Overheating and Extreme Climatic conditions on Housing Energy Comfort and Environmental Quality of Vulnerable Population in Europe. *Energy Build.* **2015**, *98*, 125–133. [CrossRef]
4. Santamouris, M. *Minimizing Energy Consumption, Energy Poverty and Global and Local Climate Change in the Built Environment Minimizing to Zero the Building Sector*; Elsevier: Amsterdam, The Netherlands, 2018.
5. Santamouris, M. On The Energy Impact of Urban Heat Island and Global Warming on Buildings. *Energy Build.* **2014**, *82*, 100–113. [CrossRef]
6. Santamouris, M.; Cartalis, C.; Synnefa, A.; Kolokotsa, D. On the Impact of Urban Heat Island and Global Warming on the Power Demand and Electricity Consumption of Buildings–A Review. *Energy Build.* **2015**, *98*, 119–124. [CrossRef]
7. Paravantis, J.; Santamouris, M.; Cartalis, C.; Efthymiou, C.; Kontoulis, N. Mortality Associated with High Ambient Temperatures, Heatwaves, and the Urban Heat Island in Athens, Greece. *Sustainability* **2017**, *9*, 606. [CrossRef]
8. Santamouris, M. Regulating the damaged thermostat of the Cities—Status, Impacts and Mitigation Strategies, Energy and Buildings. *Energy Build.* **2015**, *91*, 43–56. [CrossRef]
9. Akbari, H.; Cartalis, C.; Kolokotsa, D.; Muscio, A.; Pisello, A.L.; Rossi, F.; Santamouris, M.; Synnefa, A.; Wong, N.H.; Zinzi, M. Local Climate Change and Urban Heat Island Mitigation Techniques—The State of the Art. *J. Civ. Eng. Manag.* **2016**, *22*, 1–16. [CrossRef]
10. Santamouris, M.; Synnefa, A.; Karlessi, T. Using advanced cool materials in the urban built environment to mitigate heat islands and improve thermal comfort conditions. *Sol. Energy* **2011**, *85*, 3085–3102. [CrossRef]
11. Garshasbi, S.; Santamouris, M. Using Advanced Thermochromic Technologies in the Built Environment. Recent Development and Potential to Decrease the Energy Consumption and Fight Urban Overheating. *Sol. Energy Mater. Sol. Cells* **2019**, *191*, 21–32. [CrossRef]
12. Santamouris, M.; Feng, J. Recent Progress in Daytime Radiative Cooling: Is It the Air Conditioner of the Future? *Buildings* **2018**, *8*, 168. [CrossRef]
13. Berdahl, P.; Chen, S.S.; Destaillats, H.; Kirchstetter, T.W.; Levinson, R.M.; Zalich, M.A. Fluorescent cooling of objects exposed to sunlight—The ruby example. *Sol. Energy Mater. Sol. Cells* **2016**, *157*, 312–317. [CrossRef]

14. Taha, H. Characterization of Urban Heat and Exacerbation: Development of a Heat Island Index for California. *Climate* **2017**, *5*, 59. [CrossRef]
15. Mavrakou, T.; Polydoros, A.; Cartalis, C.; Santamouris, M. Recognition of Thermal Hot and Cold Spots in Urban Areas in Support of Mitigation Plans to Counteract Overheating: Application for Athens. *Climate* **2018**, *6*, 16. [CrossRef]
16. Karatasou, S.; Santamouris, M. Multifractal Analysis of High-Frequency Temperature Time Series in the Urban Environment. *Climate* **2018**, *6*, 50. [CrossRef]
17. Wicki, A.; Parlow, E.; Feigenwinter, C. Evaluation and Modeling of Urban Heat Island Intensity in Basel, Switzerland. *Climate* **2018**, *6*, 55. [CrossRef]
18. Jandaghian, Z.; Akbari, H. The Effect of Increasing Surface Albedo on Urban Climate and Air Quality: A Detailed Study for Sacramento, Houston, and Chicago. *Climate* **2018**, *6*, 19. [CrossRef]
19. Taha, H.; Levinson, R.; Mohegh, A.; Gilbert, H.; Ban-Weiss, G.; Chen, S. Air-Temperature Response to Neighborhood-Scale Variations in Albedo and Canopy Cover in the Real World: Fine-Resolution Meteorological Modeling and Mobile Temperature Observations in the Los Angeles Climate Archipelago. *Climate* **2018**, *6*, 53. [CrossRef]
20. Rossi, G.; Iacomussi, P.; Zinzi, M. Lighting Implications of Urban Mitigation Strategies through Cool Pavements: Energy Savings and Visual Comfort. *Climate* **2018**, *6*, 26. [CrossRef]
21. Takebayashi, H. Influence of Urban Green Area on Air Temperature of Surrounding Built-Up Area. *Climate* **2017**, *5*, 60. [CrossRef]
22. Bernard, J.; Rodler, A.; Morille, B.; Zhang, X. How to Design a Park and Its Surrounding Urban Morphology to Optimize the Spreading of Cool Air? *Climate* **2018**, *6*, 10. [CrossRef]
23. Muscio, A. The Solar Reflectance Index as a Tool to Forecast the Heat Released to the Urban Environment: Potentiality and Assessment Issues. *Climate* **2018**, *6*, 12. [CrossRef]
24. Fox, J.; Osmond, P.; Peters, A. The Effect of Building Facades on Outdoor Microclimate—Reflectance Recovery from Terrestrial Multispectral Images Using a Robust Empirical Line Method. *Climate* **2018**, *6*, 56. [CrossRef]
25. Ascione, F.; Bianco, N.; Mauro, G.; Napolitano, D.; Vanoli, G. A Multi-Criteria Approach to Achieve Constrained Cost-Optimal Energy Retrofits of Buildings by Mitigating Climate Change and Urban Overheating. *Climate* **2018**, *6*, 37. [CrossRef]
26. Georgakis, C.; Santamouris, M. Determination of the Surface and Canopy Urban Heat Island in Athens Central Zone Using Advanced Monitoring. *Climate* **2017**, *5*, 97. [CrossRef]
27. Vuckovic, M.; Maleki, A.; Mahdavi, A. Strategies for Development and Improvement of the Urban Fabric: A Vienna Case Study. *Climate* **2018**, *6*, 7. [CrossRef]
28. Laureti, F.; Martinelli, L.; Battisti, A. Assessment and Mitigation Strategies to Counteract Overheating in Urban Historical Areas in Rome. *Climate* **2018**, *6*, 18. [CrossRef]
29. Kaloustian, N.; Aouad, D.; Battista, G.; Zinzi, M. Leftover Spaces for the Mitigation of Urban Overheating in Municipal Beirut. *Climate* **2018**, *6*, 68. [CrossRef]
30. Gobo, J.; Galvani, E.; Wollmann, C. Subjective Human Perception of Open Urban Spaces in the Brazilian Subtropical Climate: A First Approach. *Climate* **2018**, *6*, 24. [CrossRef]
31. Bernard, J.; Bocher, E.; Petit, G.; Palominos, S. Sky View Factor Calculation in Urban Context: Computational Performance and Accuracy Analysis of Two Open and Free GIS Tools. *Climate* **2018**, *6*, 60. [CrossRef]