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Informed Urban Design: Minimizing Urban Heat Island Intensity via Stochastic Optimization

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Abstract : The Urban Heat Island (UHI) is characterized by increased air temperatures in urban areas compared to undeveloped rural surrounding environments. With urbanization and densification, the intensity of UHI increases, bringing negative impacts on livability, health and economy. In order to reduce those effects, it is required to take into consideration design factors when planning future developments. Given design constraints such as population size and availability of area for development, non-trivial decisions regarding the buildings' dimensions and their spatial distribution are required. We develop a framework for optimization of urban design in order to jointly minimize UHI intensity and buildings' energy consumption. First, the design constraints are defined according to spatial and population limits in order to establish realistic boundaries that would be applicable in real life decisions. Second, the tools Urban Weather Generator (UWG) and EnergyPlus are used to generate outputs of UHI intensity and total buildings' energy consumption, respectively. Those outputs are changed based on a set of variable inputs related to urban morphology aspects, such as building height, urban canyon width and population density. Lastly, an optimization problem is cast where the utility function quantifies the performance of each design candidate (e.g. minimizing a linear combination of UHI and energy consumption), and a set of constraints to be met is set. Solving this optimization problem is difficult, since there is no simple analytic form which represents the UWG and EnergyPlus models. We therefore cannot use any direct optimization techniques, but instead, develop an indirect "black box" optimization algorithm. To this end we develop a solution that is based on stochastic optimization method, known as the Cross Entropy method (CEM). The CEM translates the deterministic optimization problem into an associated stochastic optimization problem which is simple to solve analytically. We illustrate our model on a typical residential area in Singapore. Due to fast growth in population and built area and land availability generated by land reclamation, urban planning decisions are of the most importance for the country. Furthermore, the hot and humid climate in the country raises the concern for the impact of UHI. The problem presented is highly relevant to early urban design stages and the objective of such framework is to guide decision makers and assist them to include and evaluate urban microclimate and energy aspects in the process of urban planning.

Keywords : building energy consumption, stochastic optimization, urban design, urban heat island, urban weather generator
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