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An Urban Form Experiment on Urban Heat Island Effect in High Density Area

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Abstract

Urban heat island (UHI) effect is one of the most critical environmental issues for contemporary high-density cities. Previous studies show there is a strong co-relation between UHI and Sky View Factor (SVF), which constructs a potential linkage between UHI and urban forms. As cities grow denser and hotter, urban form manipulation strategies for mitigating heat island become an increasingly important challenge for urban planners and designers.
Taking high-density urban areas which have relatively high UHI intensity and low SVF value as the study subject, we develop an experiment to test the possibility of mitigating UHI through optimizing SVF of urban forms. The method adopted involves the use of digital techniques such as parametric modelling, programming and optimization algorithms. The experiment evaluates and optimizes a large number of urban form samples at both coarse and fine scales and searches out the optimum urban form for maximum or minimum SVF values under variable urban density constraints. The results of this study show that it is workable to mitigate UHI through manipulating urban form based on SVF, and indicate significant potential for urban form optimization modelling to enlighten urban planning and design decision making concerning on UHI whilst maintaining development yields

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1. Introduction

Along with global climate warming and urban population rise, urban heat island (UHI) has become one of the most critical environmental problems for high density cities [1-7]. The term, UHI describes the phenomenon that urban temperature is commonly higher than that of surrounding suburbs, because that solar radiation is stored in urban canyon at daytime, and is released in the form of long-wave heat radiation at night time [8]. A considerable body of research has revealed that heat island is closely related to urban geometry and urban materials [9,10]. Built urban form has a permanency that is very difficult to change once established. Conversely, urban materials may be improved and enhanced by means of increasing green plant coverage, water bodies, and using lighter colored and low thermal-storage materials to reduce UHI impact [11-13]. Though changes ground surfaces are relatively easy to implement, urban form has a more fundamental function in the formation of UHI and is therefore the focus of this investigation.

The value or intensity of UHI can be obtained through actual meteorological measurements, while, it may also be inferred by calculating the urban canyon using an indicator called "sky view factor" (SVF). SVF is defined to be the ratio of the visible sky area and the total sky dome of an observation point on the ground; its numerical value is 0-1, and bigger value represents better sky visibility [14]. The numerical average of SVF from all the observation points in certain area is the average SVF (av.SVF) [15-17]. Studies conducted in a wide range of different cities all over the world show that in specific areas the av.SVF has relatively high negative correlation with UHI (general expression is ⊿Tu-r=a-b*SVF; where⊿Tu-r is the UHI intensity; a is the linear coefficient; b is a constant; a, b of different cities differs) [15]. For urban development areas which have not yet constructed, the SVF calculation is valuable indicator that can be used by urban designers and planners to infer their design's potential UHI impact.

For urban planning and urban design, mitigating or adjusting the heat island of certain urban areas through manipulating or optimizing urban form has a practical environmental significance [18,19]. However, before putting forward specific optimization schemes, we put forward the following important questions: to what degree will the heat island be mitigated through urban form optimization? What kind of urban forms are conducive to UHI mitigation?

Taking high-density urban area having relatively high heat island intensity as the study subject, this paper attempts to answer the above questions by developing an experiment on urban forms.

2. Methodology

The experiment is designed to be the following form: for a set urban area, there is a specified total building gross floor area to be modeled as physical urban geometry. The task of the experiment is to find the urban form with the optimum value (maximum or minimum) of av.SVF for the specified total building area constraint. The D-value of the maximum and minimum av.SVF outlines the dimension the optimizable space of heat island. Vary the amount of total building area, the experiment will produce a series of optimum forms. Through comparison of these optimum forms, some common points from therein might be observed, and thus the general features of the optimum form could be summarized.

One challenge for calculation in the experiment is that for a same total building area, there is an almost infinite quantity of possible urban forms, which compose the so-called "solution space". It is not feasible to test all possible forms and so an effective search method is needed to find the optimum form (or the form close to optimum value) from the solution space. The experiment proposes a scheme of two stage optimization to address this calculation challenge (Fig. 1): Firstly, on a relatively coarse scale, urban forms are simplified as a group of boxes with different sizes on plots. We call this simplified form the "density distribution form". Various iterations of density distribution form for the total building area onto plots were first generated randomly as the initial samples. Then, we refined these samples by applying an optimization algorithm finding the sample with the optimum UHI intensity.

Based on the optimum density distribution form found in the first stage, the experiment moved to the second stage on a fine scale. The simplified boxes at the last stage were re-modeled into diversified possible building volume forms according to the architectural rules and conventions for the layout of high-rise building complexes in the context of China. Optimization of these building volume forms was then performed, finding the building form sample for optimum UHI intensity value.

The abovementioned scheme is based on the hypothesis: Density distribution form reflects rough urban form contour and trend, and the optimum building form obtained from the optimum density distribution form is better than