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Simulation Study of Urban Residential Development and Urban Climate Change in Xi'an, China

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Abstract

Increased awareness of the urban heat island (UHI) effect has drawn attention to monitoring and evaluating outdoor thermal comfort in cities worldwide. Especially in China, rapid, large-scale urban development is producing urban climate change in large cities, creating other urban environmental problems such as haze weather. Currently, studies are being conducted in China to reveal the impact of urban development on urban climate change. Few studies, however, have focused on microscale urban planning styles and urban typology.

High-density building development will change the urban typology, leading to changes in the urban sky view factor (SVF) and microclimate. Our previous study explored the relationship between SVF and the UHI effect by assessing the effect of SVF on the urban thermal environment. Since the energy consumed by indoor heating and air conditioning is affected by mean air temperature (Ta), a high SVF should be considered in the urban planning stage. In this study, we analyzed typical urban planning styles in China. We selected microscale residential districts in Xi'an to represent the typical urban typology of residential districts that developed during different periods and used the numerical urban simulation system ENVI-met to evaluate the impact of urban typology change on urban climate change. Using this approach, we determined the effects of building density, building styles, and vegetation system design, thus demonstrating the mechanism of urban climate change in China's larger cities. This analysis of planning styles can provide guidance for future environmental urban development.

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Keywords: urban planning; urban climate change; environmental simulation; urban typology

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1. Introduction

High-speed, high-density urban development has contributed to urban environmental problems, including climate change, increased energy consumption, and haze weather. Such effects are observed in large Chinese cities such as Xi'an. Given these urban environmental problems, sustainable urban development is becoming an important task in China. However, there remains a lack of mechanism studies investigating urban geometry and urban climate change.

1.1. Urban climate change in cities

In recent years, urban climate change has been observed in most of the world's developed cities. Between 1961 and 1980, the annual air temperature rose 0.36oC in central Beijing. However, during the building boom between 1981 and 2000, it rose 0.94oC [1]. The correlation coefficient between the impervious surface rate and land surface temperature in Beijing reached 0.93 [2]. Climate models indicate that, due to the expected warming of up to 9oC by the 2080s in the Arctic and the southern and central Prairies [3], the number of days with average temperatures above 30oC is likely to increase in cities across Canada, especially those in the Windsor–Quebec corridor (such as Toronto) and portions of British Columbia. Thus, urbanization patterns, especially in the central parts of cities, have a large impact on urban climate change. The spatial variability of urban heat islands (UHIs) in cities has been found to be a function of urban surface properties, which in turn are influenced by land cover, especially vegetation cover and building density [4].

The deep urban canopy created by high-rises can increase the wind speed in urban areas and affect the urban thermal environment. A simulation comparison of high-rise and low-rise buildings in the Lujiazui district of Shanghai found that with low-rise buildings, wind speed declined 22%, air temperature decreased 7%, and O3 decreased 9% [5]. Another study used wind tunnel measurements to examine wind velocities in Toronto, confirming that among several high-rise towers, wind often accelerated above 10 m/s; this created wind-chill effects and exerted mechanical forces on pedestrians, making it unsafe for them to walk [6]. The openness of urban geometry can be defined using the sky view factor (SVF). The correlation between SVF and the urban thermal environment has been demonstrated in Montreal, Canada [7, 12, 13]. A high SVF, which means more open urban space, could be related to a lower UHI index.

Urban development largely serves the purposes of economic development. Especially in China, large-scale, rapid urban development mostly focuses on the operational efficiency of cities, with little attention to the long-term environmental effects. This is a major cause of China's current environmental crisis, and the problem is rapidly spreading to India as well as other countries of Southeast Asia and the Middle East.

1.2. Different periods of building development in Xi'an

Xi'an is a historical city as well as one of the most developed cities in China's central plains. Most of the current urban buildings were constructed after 1979 [8]. Different development styles and residential building types can be observed for the different periods of rapid urban development.

Between 1979 and 1989, the Chinese government started to focus on economic development and infrastructure. Along with the redevelopment of existing urban areas, new construction was carried out on the edges of central urban areas. To meet the residential demand in the city, large factories developed residential areas nearby for staff and workers. Most buildings built during this period are five to six stories, though some have seven floors.

After 1990, real estate developers started to have a major impact on urban reform and urban expansion. New, large-scale developments started occurring outside the city core. During this period, building design and quality became more important than in the past. Most buildings were still five to seven stories, but high-rises and detached houses were also developed in some of the projects.

Since 2000, the high-rise has become the most common construction style in residential development projects. The purpose of residential development has shifted from meeting the basic needs of citizens to promoting real estate and the urban economy. Fig. 1 shows the process of urban expansion in Xi'an. It is clear that urban occupation has grown rapidly. Meanwhile, urban building density has also increased because of the high building density of recent development projects.