

China's experience in responding to urban heat island

PHẠM NGỌC ĐĂNG
 Vice President of VACNE
 TRẦN THỊ MINH NGUYỆT
 Hanoi University of Civil Engineering

1. URBAN HEAT ISLAND (UHI) INCREASES COOLING ENERGY CONSUMPTION IN CHINA

China has a North-South length of about 5,500 km and an East-West width of about 5,000 km, with an area of 9,597 km², ranking 3rd in the world, after the Russian Federation (17,075 km²) and Canada (9,971 km²), 30 times larger than Vietnam. China's population has surpassed 1.4 billion people, the largest in the world and 15 times larger than Vietnam [1]. China has five main climate types, including: Temperate continental climate; temperate monsoon climate; subtropical monsoon climate; tropical monsoon climate; highland mountain climate.

Over the past 40 years, the urbanization rate in China has developed rapidly, ranking first in the world, the urban population has increased from about 200 million to about 700 million [2]. According to World Urbanization Prospects (2024), the urban population ratio of China in 1980 was only 19.4%, increased to 36.2% in 2000 and reached 50% in 2010. It is forecasted that by 2050, the urban population ratio of China will reach 80% (Table 1).

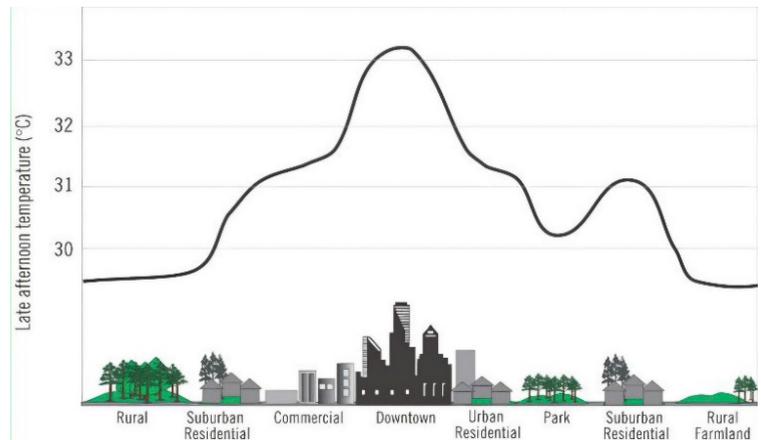
Table 1. Urbanization rate in China over the past 40 years

Year	1980	1990	2000	2010	2020	2050
% urban people	19,4	26,4	36,2	50	61,4	Forecast 80

China's rapid urbanization has also led to remarkable economic growth. Estimates from the 2023 Global Digital Economy Conference show that the size of China's digital economy has increased to 50.2 trillion yuan (about 6.96 trillion USD) by 2022, with an annual double-digit growth rate of 14.2% since 2016, China's current gross domestic product ranks second in the world after the United States. However, economic development along with increasing urban construction density gives rise to urban heat island effects (Urban Heat Island - UHI) [2]. According to Jump up to: "Glossary". Climate Change (2022) defines UHI as "The relative otherness of a city compared to surrounding rural areas" [1].

In many urban areas of China, especially those in subtropical and tropical monsoon climates, much of the urban land area for planting trees and wetlands

Figure 1. Temperature variation across urban and rural areas (US. EPA, 2008)



due to urbanization has been converted into concentrated construction land, increasing the surface area for absorbing solar radiation (SIR). In addition, the amount of artificial heat waste from urban cooling equipment (air conditioning systems); transportation activities; industrial production and other manufacturing industries... has made the temperature in urban areas higher than the temperature in surrounding rural areas. This is the UHI phenomenon, increasing greenhouse gas emissions (CO₂) and accelerating climate change (CC) [1].

(Source: [2])

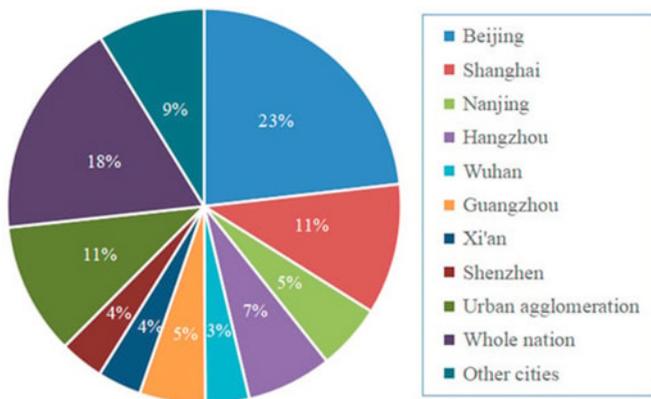
Over the past 15 years, many cities in China have increased UHI, mainly in the eastern and southern regions. Therefore, hundreds of scientific research works on UHI in China have been carried out, with the following four methods: (i) Meteorological observation method is a method that uses long-term meteorological data from both pre- and post-urbanization periods, as well as urban and suburban meteorological data in the same period; (ii) Using fixed measurements or the horizontal measurement method is a method that uses mobile or horizontal mini weather stations focusing on short-term data to assess UHI; (iii) The remote sensing method is performed using thermal images from satellites, commonly used satellite data are MODIS (1 km), ASTER (90 m), Landsat-5-TM (120 m), Landsat-7-ETM+ (60 m) and Landsat-8-OLI/TIRS (100 m); Among them, many researchers use MODIS and Landsat TM/ETM+/OLI data to study UHI with open access to data collection and spatial coverage of the study area; (iv) Numerical simulation methods are methods to predict various environmental parameters (e.g., temperature, humidity, and wind speed) in urban spaces. Actual air temperature or



surface temperature measurement data are often used as boundary conditions in numerical simulation calculations, and the results of numerical simulation studies are compared with measured data for analysis and optimization [2,3,4,5,6,7]. Among them, remote sensing method is applied the most by Chinese scientists to study UHI. Most of the studies on UHI in China in recent times have used remote sensing method. According to Chart 2, the proportion (%) of UHI studies using remote sensing methods is distributed by locality as follows: Beijing (11%); Shanghai (11%); Nanjing (11%); Wuhan (11%); Guangzhou (5%); Xi'an (9%); Hangzhou (4%); Shenzhen (4%); Yangtze River Delta Urban Cluster (18%); research on national issues (7%) and in other urban areas (9%) [2].

China has also led to a significant increase in energy consumption. According to statistics, energy demand in construction in China accounted for about 24.1% of the total national energy use in 1996, reaching 27.5% in 2010, increasing to 35% in 2020 [2]. Studies around the world have shown that energy consumption of construction works accounts for about 47% of

Figure 2. Proportion (%) of UHI studies using remote sensing methods distributed by locality, based on analysis of hundreds of scientific research works on UHI published in China in the past 15 years [2].



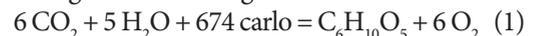
total primary energy consumption in Switzerland; 42% in Brazil; 40% in the USA; 39% in the UK; 25% in Japan and 23% in Spain [2]. The UHI effect is considered as one of the important factors that increase building energy consumption due to increased space cooling demand in summer and space heating demand in winter [3]. Li et al. [3] reviewed the existing literature on the impact of UHI on building energy consumption and found that UHI increased the average cooling energy consumption by 19.0% at the national, regional and global levels. The impact of UHI on building energy consumption depends largely on the local climate, as well as the type and characteristics of the building. Compared to rural areas, UHI in urban areas of Beijing increased cooling by 11% and heating by 16% [4]. Similarly, the UHI effect increased air conditioning energy demand by about 10% in Hong Kong. In addition, the impact of UHI on building energy consumption varies according to building type. Studies in Nanjing, China (2017) [4] showed that the cooling load of office buildings increased by 4.0 - 7.1%, while the cooling load of apartment buildings increased by 11.2 - 25.2%. The impact of UHI on building energy consumption also differs between urban centers and urban suburbs. Research results by Chu et al., 2017 show that the heat load index of buildings located in the city center in winter is 1.5-5.0% lower than that of buildings in the suburbs [4].

2. SOLUTIONS TO MITIGATE THE IMPACT OF URBAN HEAT ISLANDS IN CHINA

2.1. Development of urban green space

Developing urban green spaces is an important solution widely applied in China to cool the city by natural, sustainable measures and prevent the formation of UHI. Trees have the effect of shading, absorbing solar radiation (SIR), reducing ambient air temperature and ground temperature, reducing energy costs for air conditioning.

In addition, trees have the effect of absorbing dust, smoke and some toxic chemicals that pollute the air environment, reducing noise. During the day, trees absorb CO₂, absorb heat from the environment and absorb underground water, releasing O₂ according to the following reactions:



Thus, the chlorophyllization process of green trees will increase the amount of O₂ in the air (increase by about 20%) and reduce the concentration of CO₂ in the surrounding air. Therefore, to cope with the UHI effect, it is necessary to first ensure the minimum green area ratio in urban areas. Urban greening can clean the air, regulate temperature, regulate local climate and improve the city's ecosystem. There have been many studies evaluating urban greening measures to protect human health when urban temperatures increase rapidly [1].

Landscape planning and development of urban green spaces (UGS) including parks, flower gardens, street trees, green spaces in campuses, agencies and public works... can form the urban cooling island effect (UCI). Research by Tan et al. (2015) found that small parks with lots of trees are green spaces that significantly reduce urban air temperatures. Research by Yan et al., 2018, shows that the cooling effect of parks can extend beyond the park border by nearly 1.4 km; Research by Chang et al. (2014) shows that the larger the park size, the stronger the regional cooling effect.

2.2. Green Roof (GR)

Green Roof (GR), also known as eco-roofs, living roofs and rooftop gardens, has great potential to impact the urban environment, as rooftops account for nearly 20-25% of a city's surface area. In China, where the majority of buildings in some major cities such as Beijing, Shanghai, Chongqing and Hong Kong are densely packed, the deployment of GR helps save energy, reduce noise and air pollution. Although GRs increase the initial investment compared to traditional roofs, they mitigate the UHI effect in urban areas because green vegetation can significantly change albedo values and reduce heat transfer to buildings. A sensitivity test by He et al (2017) showed that better thermal performance in both summer and winter can be achieved by



increasing the substrate thickness or using GR on uninsulated buildings. The study by Tam et al [6] showed that GR can reduce the indoor temperature on the top floor by up to 3.4°C, with the cooling effect of GR being strongest in summer and weakest in winter for the Shanghai area.

2.3. Cool roof

Cool roofs are roofs with solar panels installed and covered with materials with high solar radiation reflectance (SAR) Albedo coefficient. In China, the installation of solar panels on all roofs is encouraged, both to supplement renewable energy sources and to reduce the thermal load on building cooling equipment, resulting in effective reduction of UHI effect and CO₂ emissions. Coating roofs with highly reflective solar radiation coatings has been shown to be an effective measure to reduce heat gain. Calculations also show that a vinyl roof reflects at least 75% of the sun's rays and emits at least 70% of the solar radiation absorbed by the building envelope. In contrast, asphalt roofs have a solar reflectance of only 6% to 20% [9]. When installed on rooftops in dense urban areas, passive radiant cooling panels can significantly lower outdoor air temperatures during the day. Green roofs provide insulation during hot months and can also have a positive impact on stormwater management and reduce energy costs for cooling buildings.

2.4. Green trees on the facade of construction works

Green plants on building facades are also called “vertical greening systems”, “vertical gardens”, “green walls” and “bio-walls”. This model is becoming more and more popular in China because of its small scale, high aesthetic value and good UHI reduction ability. These effects can further benefit psychological well-being and reduce noise, protect the building envelope and provide biodiversity. Greenery on building facades can reduce wall temperatures to save energy through interception of solar radiation, insulation due to vegetation, evaporative cooling and acting as a windbreak. Yin et al. (2017) found that trees on building facades can significantly reduce the surface temperature of building facades by up to 4.67°C and the cooling effect of trees on building facades is most obvious at noon. Research by Cheng et al. (2010) showed that building envelopes with green facades reduce air conditioning energy consumption and the cooling efficiency is closely related to the green coverage area and humidity in the growing environment. Pan et al. (2016) showed that greenery on building facades can save 16% of total electricity consumption. A study on applying greenery on building facades for high-rise apartment buildings showed that greenery on building facades can reduce 2651 × 106 kWh of electricity and 2200 × 106 kg of carbon dioxide emissions per year (Wong and Baldwin, 2016). Different types of trees have different characteristics including plant species, leaf area, canopy thickness, etc., of which canopy thickness is considered the most important factor affecting the thermal performance of trees on building facades. In addition, the maximum surface temperature of walls with trees on facades is reduced by 6.3°C compared to walls without trees. Building orientation, climate and weather contribute significantly to the thermal performance of trees on building facades.

2.5. Appropriate urban planning and construction form

Urban planning determines urban form and affects urban climate, and conversely, urban climate can be adjusted and improved through urban planning to meet the needs of people.

Urban planning and urban design have practical environmental implications to minimize the UHI effect of some urban areas by adjusting or optimizing urban form. Urban scale, urban geometry and vegetation coverage are the most basic urban morphological factors affecting the urban thermal environment. From the perspective of mitigating the UHI effect, China has planned the development of small cities, medium-sized cities and large cities with multi-centers and multi-directional development. From the perspective of minimizing the UHI effect, small and medium-sized cities and large multi-centered cities should be planned to develop in a strip-like direction, in accordance with the hydrological network, taking into account the enhancement of green areas with various plant species. The main structures should be oriented parallel or slightly oblique (no more than 15 degrees) to the main wind direction of the city. In addition, urban development planning needs to preserve and expand green areas and water surfaces to reduce UHI generation. Ensure that at least 40% of public urban spaces have shade from trees. On the other hand, planning the direction of roads in urban areas to maximize natural ventilation, create air flow patterns through neighborhoods, shape wind corridors, and promote biodiversity development to minimize UHI formation during the hot season. Rows of trees on urban streets need to have thick, wide canopies and be about 10-15 m high so that the trees can both provide good sun protection and not obstruct the wind flow easily through the streets. Arranging clusters of buildings in a linear layout is more effective in cooling the city than a “U” or “□” layout. The UHI effect will be mitigated by using white materials or materials that reflect solar radiation on walls, roofs, sidewalks and roads [7].

2.6. Cool sidewalks and roads

The pavement and road surface have changed the original thermal properties of the natural ground, and when the pavement and road surface temperature increases, the air temperature near the pavement and road also increases, causing the UHI effect. Chinese studies have recommended specific solutions to cool the pavement and road surface: Qin et al. (2015) recommended that reflective pavement and road surfaces should be used when the aspect ratio of urban alleys is less than 1.0 m. Ziang et al. (2019) [9], designed a solar reflective coating to cool pavement and asphalt pavement. Experimental results show that the reduction in surface temperature of sidewalks and roads is about 8.5°C - 9.5°C. Luu et al. (2018) showed that permeable sidewalks and roads help reduce street flooding when it rains, and when it is sunny, water seeps from the ground to the surface, evaporates, and absorbs heat from the BXMT, so it contributes



greatly to reducing UHI, with a maximum cooling level of 9.4°C compared to traditional sidewalks and roads. In addition, Giang et al. (2018) designed a road-based thermoelectric generator system that can convert or transfer road surface heat into electricity, lowering the surface temperature by 8 - 9°C in summer.

2.7. Urban water surfaces

Urban water bodies are one of the main components of urban areas, with high thermal capacity and low thermal conductivity, which can effectively mitigate the UHI effect. Urban water bodies mainly include rivers, canals and reservoirs, forming urban cool areas. Yang et al. (2016) showed that rivers and lakes in Bozhou, China are the main source of urban cooling in summer. Wang et al. (2014) showed that wetlands have a good temperature-regulating effect, and the closer the urban area is to wetlands, the more significant the urban temperature-regulating ability is. Xue et al. (2019) showed that the average cooling capacity index of wetlands in Changchun City (China) was 2.3 times higher than that of conventional urban land, and the average cooling value of wetlands with flows connected to other surface water bodies was 6 times higher than that of isolated wetlands. Du et al. (2017) found that urban rivers change the surrounding air flow and the UHI near the river is lower. By studying the effect of artificial ponds on the urban thermal environment using experimental methods, Syafii et al. (2017) found that urban environments with ponds are better than urban environments without ponds, especially during daytime hours, and ponds arranged with larger surface areas show better cooling effects.

2.8. Urban ventilation

Urban ventilation, which takes advantage of wind characteristics to bring fresh air from the suburbs into the city, is considered one of the main mitigation strategies to reduce the UHI effect. In addition to removing heat, urban ventilation is also important for improving living environment quality, eliminating air pollution and saving energy. For example, in a new district of Shenzhen, the initial actual urban development did not use the urban ventilation scheme, which resulted in the blocking of urban wind channels and enhanced the UHI effect. Research results of many authors suggest that the increase in near-ground air pollution in Chinese cities and the frequent occurrence of smog during winter in China, as well as the increase in UHI effect in summer are all related to poor ventilation in cities, so urban ventilation planning is very necessary. Xu et al. (2016) analyzed the spatial distribution of UHI and cool sources based on the daily average temperature distribution map of typical meteorological conditions and proposed

the planning of urban ventilation channels to reduce UHI. Based on the urban expansion model of Dalian City (China) with high construction density, leading to a decreasing trend in annual wind speed, Guo et al. (2017) studied the natural ventilation performance evaluation of different building types using a fluid dynamics computational simulation tool. The research results show that urban areas, such as row houses and high-rise buildings with large foundations, are not conducive to natural ventilation, while reasonable planning and measures such as open urban space, creating ventilation channels, appropriately increasing building height, reducing the foundation volume of high-rise buildings, adopting reasonable building shapes and reducing building facade areas all have significant effects on promoting urban ventilation and alleviating the UHI effect ■

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