Review of Sustainable Urban Planning and Design Policy Interventions for Heatwave Management in Urban Environments

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Abstract

Climate change leads to frequent extreme temperature events, making cities vulnerable to severe heatwaves. Therefore, this study aims to provide a systematic and overarching review of the urban planning and design policy interventions for heatwave management. This study used a series of key terms to search for relevant studies in three databases, including Web of Science, ScienceDirect, and Wiley and then identified 28 articles published between 2007 and 2023 after several inclusion and exclusion criteria. After a systematic review, 15 policy interventions for heatwave management were summarized from the built environment level and building level. Cooling mechanisms and scope of application were discussed. The results of this study provide policymakers with comprehensive guidance on sustainable urban design and planning for heatwave management.

Keywords: Heatwave management, Sustainable urban planning and design, Policy interventions, Adaptation strategies, Urban environment

1 Introduction

Increasing global temperatures and frequent heatwave events have significantly driven up cooling energy demand, particularly in the residential sector, which comprises an average of 14.7% of annual home energy use in the U.S. (Feng et al., 2021). Heatwaves usually refer to events with extremely high air temperatures that last for several days, causing huge losses to urban systems, (Lau & Nath, 2012). To mitigate the negative impacts of heatwaves, a series of policy interventions and related adaptation strategies from the behavior perspective has been adopted (Kiarsi et al., 2023). Long-term strategies consisting of urban planning and infrastructure, including climate-responsive housing, have not yet been incorporated into existing mainstream heatwave management plans (Pathak, Shukla, Garg, & Dholakia, 2015). However, with urbanization and urban renewal, it is difficult to simply consider adaptive behaviors to achieve the goal of improving urban thermal resilience. From a positive perspective of leveraging urbanization, sustainable urban planning and design strategies that incorporate green spaces have been called for to minimize the adverse effects associated with heatwaves (Kabisch, Strohbach, Haase, & Kronenberg, 2016).

Although increasing studies have begun to focus on policy interventions or adaptation strategies for sustainable urban planning and design, these existing interventions for heatwave management are still fragmented and unsystematic (Yadav, Rajendra, Awasthi, & Singh, 2023). Specifically, these interventions target different groups, scopes, and implementation objects, but are released in a

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disorganized and mixed manner, which may lead to confusion and hinder their effectiveness as guidance. For example, the cooling strategies proposed by the U.S. Environmental Protection Agency (EPA) include measures for individual buildings, such as installing green roofs, and measures for the urban built environment, such as using cool pavements (U.S. Environmental Protection Agency, 2023). A mix of released urban planning and design policy interventions will not be conducive to guiding urban managers at all levels and the public to participate in sustainable urban planning, design, and renewal in response to heatwaves. Therefore, it is necessary to extract and systematically sort out policy interventions to provide policymakers with comprehensive sustainable urban planning and design guidelines for heatwave management.

This study aims to provide a systematic and overarching review of sustainable urban planning and design policy interventions for heatwave management in urban environments. For this purpose, related papers were reviewed to extract effective planning and design policy interventions and classified from the perspectives of urban built environments and buildings.

2 Methodology

This study compiles and examines peer-reviewed papers related to policy interventions for heatwaves. The publications were selected from three databases, including Web of Science, ScienceDirect, and Wiley. Referring to the research of Kotharkar & Ghosh (2021), several key terms are used, including "heatwave", "adaption policies", "cooling strategies", etc. Through the initial search and quick screening, this study obtained 69 records. We reviewed the full texts of these potentially relevant studies and screened them for inclusion according to three criteria: research content, article type, and language. After screening, this study identified 28 articles published between 2007 and 2023. The flowchart of the selection of literature is shown in Figure 1.

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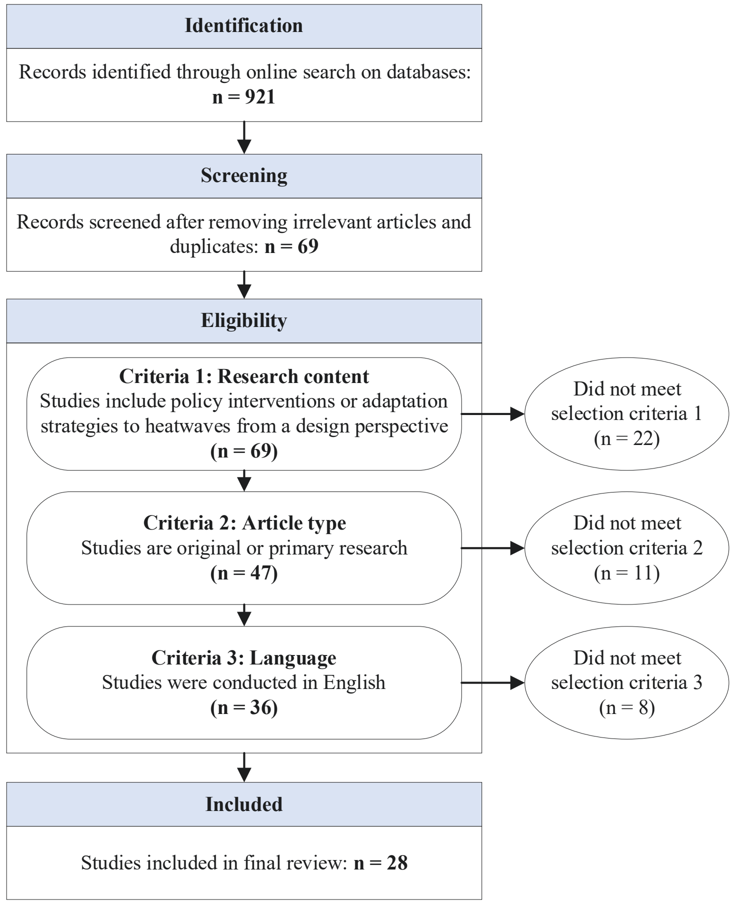

Fig.1 Flowchart of the selection of literature

3 Policy Interventions for Heatwave Management

After a systematic review, existing urban planning and design policy interventions can be divided into two categories according to their scope: those that improve the urban built environment outside the building and those that improve buildings inside, as shown in Table 1. Further, different policy interventions use different cooling mechanisms, which can be divided into five main types: *evaporation*, *reflection*, *insulation*, *cooling*, and *shade*.

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Table 1. Summary of existing design policy interventions

Scope	Specific measures	Mechanism	Source
Urban built environment	Use of green and blue space	Evaporation	(Cui, Yin, Cheng, Tang, & He, 2024; Eum, Kim, Jung, & Rho, 2018; Gunawardena, Wells, & Kershaw, 2017)
	Urban greening: roadside planting	Evaporation	(Badura, Krkoška Lorencová, Ferrini, & Vačkářová, 2021; Zanocco & Sousa-Silva, 2023; Ziter, Pedersen, Kucharik, & Turner, 2019)
	Restoration of urban ecosystems, including biotope creation	Evaporation	(Eum et al., 2018)
	Ecological river restoration	Evaporation	(Eum et al., 2018)
	Use of permeable surfaces	Evaporation	(Badura et al., 2021; Wang et al., 2019)
	Outdoor shade spaces and shade screens	Shade	(Hong, Min, Lee, & Choi, 2022)
	Use of cool/reflective material materials on urban surfaces	Reflection	(Zanocco & Sousa-Silva, 2023)
Building	Green roofs	Evaporation	(Badura et al., 2021; Cui et al., 2024; Eum et al., 2018; Liu, Tian, Feng, Hou, & Ma, 2022)
	Green walls	Evaporation	(Badura et al., 2021; Cui et al., 2024; Eum et al., 2018)
	Cool roofs	Reflection	(Burlotos, Dresser, & Shandas, 2023; Liu et al., 2022; Santamouris, Synnefa, & Karlessi, 2011)
	Cool/reflective material	Reflection	(Cui et al., 2024; Santamouris et al., 2011; Zanocco & Sousa-Silva, 2023)
	Attic and cavity-wall insulation retrofits (additional insulation)	Insulation	(Jahani & Cetin, 2022; Porritt, Cropper, Shao, & Goodier, 2013)
	Cooling system efficiency improvement	Cooling	(Jahani & Cetin, 2022)
	Cool loop installation	Cooling	(Eum et al., 2018)
	Installing shutters	Shade	(Porritt et al., 2013)

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4 Discussion

4.1 Policy Interventions at the Urban Built-Environment Level

As shown in Table 1, the existing policy interventions or adaptation strategies for heatwave management at the urban built-environment level mainly include seven pathways: use of green and blue space, urban greening, restoration of urban ecosystems, ecological river restoration, use of permeable surfaces, expanding outdoor shade spaces and shade screens, and use of cool or reflective material materials on urban surfaces. The cooling mechanisms of these policy interventions mainly include *evaporation*, *reflection,* and *shade*, the majority of which are nature-based strategies.

Use of green and blue space mainly refers to the evaporation of water through plants, transferring urban surface heat to the atmosphere to cool the city (Badura et al., 2021). This strategy has a significant cooling effect during heatwaves. For example, green spaces can reduce the average temperatures of their surroundings by 1.1°K in summer and up to 4°K at night (Gunawardena et al., 2017). Based on these fundamental strategies, the thermal-environment improvement policies presented by South Korea in the First Implementation Plan for Climate Change Adaptation Measures (2012–2016) also included the restoration of urban ecosystems and the ecological river restoration (Eum et al., 2018).

However, these interventions are often restricted by the urban original ecological characteristics. Therefore, increasing studies focus on small-scale urban greening, i.e. increasing vegetative cover in urban built environments. In particular, planting street trees has been widely supported by the public (Zanocco & Sousa-Silva, 2023). According to Ziter et al. (2019), the temperature decreases nonlinearly with the increase of canopy coverage of street trees and the cooling effect is best when the canopy coverage exceeds 40%. This intervention combines two cooling mechanisms, *evaporation* and *shade*, which can effectively reduce the temperature while limiting the increase in economic costs. Similar shading interventions include expanding outdoor shade spaces and shade screens (Hong et al., 2022).

In addition, urban surfaces that are difficult to cover with vegetation, such as pavements, also need to be considered to increase adaptability to heatwaves. Given the principle of *evaporation*, permeable pavement with high water absorption capacity is also conducive to enhancing evaporation and reducing surface temperatures, which was considered to be one of the effective strategies for dealing with high temperatures (Wang et al., 2019).

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However, effective permeable pavement materials are still in the experimental exploration stage and have not been widely promoted. Therefore, instead of using *evaporation*, many studies explored the use of highly reflective materials on urban surfaces (called ‘cool surfaces’), such as cool pavements formed by applying reflective coatings on the surfaces (Zanocco & Sousa-Silva, 2023). This type of material enables urban surfaces to have high solar reflectance (or albedo) and high thermal emittance characteristics that might leave them cooler than surfaces constructed with traditional building materials (Maggiotto, Miani, Rizzo, Castellone, & Piscitelli, 2021).

4.2 Policy Interventions at the Building Level

As many existing residences can no longer meet the needs of dealing with heatwaves, the majority of existing urban planning and design policy interventions or adaptation strategies for heatwave management focus on the retrofits of buildings. After a systematic review, policy interventions at the building level include eight pathways: green roofs, green walls, cool roofs, use of cool or reflective material, attic and cavity-wall insulation retrofits, cooling system efficiency improvement, cool loop installation, and installing shutters.

As representative adaptation strategies at the building level, green and cool roofs have been proven to have good cooling effects during heatwaves. For example, during heatwaves, the absolute cooling intensities of cool and green roofs were 0.06°C and 0.03°C respectively (Liu et al., 2022).

It is worth noting that the effectiveness of a green roof depends largely on the moisture level of the soil (Krayenhoff et al., 2021). This also means that the cooling effectiveness of green roofs and green walls will be limited by the growing environment of the plants used and are only suitable for cities or regions with high precipitation or high humidity, such as Singapore.

Therefore, for buildings where green roofs cannot be installed, we consider cool roofs to be an alternative effective intervention to deal with heatwaves. Cool roofs were also proposed to increase the surface albedo by using advanced materials or coatings to reduce the building roof-surface capture of solar radiation (Liu et al., 2022). In addition to such cool-roof interventions, the application of advanced cool materials to other building coatings and structures has also been widely explored (Santamouris et al., 2011). These materials are specifically developed to respond to the solar infrared portion, which has been identified as the most impactful component for building energy efficiency and indoor thermal conditions (Song et al., 2020).

In theory, attic and cavity-wall insulation retrofits can reduce the rise in indoor temperatures due to heatwaves by blocking or reducing heat transfer, which is also regarded as an important policy intervention for housing retrofit projects to deal with heatwaves (Jahani & Cetin, 2022). However, this intervention is not suitable for all house types. For example, cavity-wall insulation is not suitable for old solid wall terraced houses. It is also difficult for modern, well-insulated houses to benefit from upgraded insulation (Porritt et al., 2013). Therefore, compared with attic and cavity-wall insulation retrofits, installing shutters has been widely adopted as an easy-to-operate alternative intervention that can reduce the increase in indoor temperature due to heatwaves by reducing direct solar radiation (Porritt et al., 2013).

Unlike the above slow and indirect cooling mechanisms, optimization of the cooling system can often directly and quickly achieve cooling, including cooling-system efficiency improvement (Jahani & Cetin, 2022) and cool loop installation (Eum et al., 2018). However, these types of design policy interventions have high economic costs that may limit their adoption and promotion (Porritt et al., 2013), especially for low-income groups.

5 Conclusion, Iimplications, and Llimitations

This study systematically summarizes 15 policy interventions for heatwave management from the perspectives of urban built environments and buildings that are categorized into five types according to their cooling mechanisms. The applicability, scope, and constraints of these interventions were discussed, providing valuable insights and guidelines for policymakers on formal policy implementation that can effectively coordinate relevant organizations to carry out cross-departmental efforts while increasing public participation to develop sustainable cities.

However, sustainable urban planning and design policy interventions for heatwave management may conflict with other policies. For example, green walls may conflict with building regulations for wall appearance. Therefore, future research is expected to consider coordination between policies. In addition, with the development of technology and the update of materials, more design strategies that can contribute to resisting heatwaves and saving energy will be implemented. For example, the reversible photothermal windows proposed by Jahid et al. (2022) were expected to dynamically adjust solar heat according to weather conditions. It is worth noting that since policy interventions increase the economic cost to the public, future research is expected to further explore how to effectively attract the public to implement these measures.

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