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Eureka Journal of Civil, Architecture and Urban Studies (EJCAUS)
ISSN 2760-4977 (Online) Volume 2, Issue 6, June 2026

https://eurekaoa.com/index.php/8

ENHANCING THERMAL COMFORT IN URBAN BUILDINGS THROUGH PASSIVE DESIGN STRATEGIES: REDUCING OVERHEATING WITHOUT MECHANICAL SYSTEMS

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Abstract

The problems related to the urban environment have become increasingly critical in the context of climate change. It requires a reconsideration of contemporary approaches to urban planning and architectural design. This issue is particularly urgent in regions with extremely high temperatures, where rapid urbanization intensifies climatic stress on cities. For example: Central Asia.

One of the main factors contributing to urban overheating is population growth and the concentration of infrastructure within dense urban areas. The extensive use of vehicles, industrial equipment, and heat-absorbing materials such as concrete and asphalt leads to the accumulation of solar radiation during the day and limits natural cooling at night. Consequently, urban spaces experience prolonged periods of elevated temperature.

Conventional solutions to overheating often depend on air conditioning systems. While these systems help cool indoor spaces, they require large amounts of energy and release additional heat into the surrounding environment. As a result, the use of air conditioning can actually increase urban temperatures and make the overheating problem worse.

This article examines passive design strategies aimed at reducing heat loads on urban buildings while minimizing reliance on electrical systems. Emphasis is placed on passive cooling techniques, climate-responsive materials, and the

ISSN 2760-4977 (Online) Volume 2, Issue 6, June 2026

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integration of vegetation into the built environment. These approaches not only improve indoor thermal comfort but also contribute to better air quality and more sustainable urban ecosystems. The study argues that passive design represents a key pathway toward achieving thermal comfort and environmental balance in cities located in hot climatic regions.

Keywords: Passive design, thermal comfort, vernacular architecture, urban buildings, overheating, sustainable architecture, natural ventilation, human-centered design, green building, energy efficiency, heat island effect.

Introduction

Urbanization is one of the defining processes of the twenty-first century. As cities continue to expand and densify, the built environment increasingly influences local climate conditions and indoor comfort levels. High building density and reduced vegetation contribute to the urban heat island effect, which significantly increases ambient temperatures in cities compared to surrounding rural areas. Therefore, urban buildings are becoming more vulnerable to overheating, particularly during summer months.

As indoor temperatures continue to rise, many buildings rely on mechanical cooling systems such as air conditioning to achieve thermal comfort. These systems are effective in reducing heat, but they consume large amounts of energy and increase operating costs. In addition, the widespread use of air conditioning contributes to higher greenhouse gas emissions, especially in rapidly urbanizing and developing regions where energy resources may be limited.

Thermal comfort plays an important role in indoor environmental quality, as it affects occupants' health, comfort, and productivity. However, maintaining comfortable indoor conditions without excessive energy use remains a major challenge in contemporary architecture and urban design. For this reason, passive design strategies are increasingly considered as an alternative solution. These

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ISSN 2760-4977 (Online) Volume 2, Issue 6, June 2026

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strategies rely on natural elements such as solar shading, building orientation, natural ventilation, vertical gardening, and thermal mass (the ability of a material to absorb, store and release heat) to control indoor temperatures.

The aim of this article is to examine passive design strategies that improve thermal comfort in urban buildings and help reduce overheating without the use of mechanical cooling systems. By reviewing existing studies and architectural examples. It discusses how passive solutions can be applied in dense urban environments and why they are important for sustainable urban development.

Urbanization and Overheating

Numerous studies have identified urbanization as a major factor contributing to higher outdoor and indoor temperatures (Oke, 1982; Santamouris, 2015). Dense building layouts, narrow street canyons, and large paved surfaces reduce natural airflow and limit heat dissipation. As a result, urban areas absorb more solar radiation during the day and release it slowly at night, leading to prolonged periods of elevated temperatures.

The urban heat island effect further explains why cities are often several degrees warmer than surrounding rural areas (Oke, 1982). This temperature difference increases cooling demand in buildings and intensifies indoor overheating. In compact urban environments, the lack of vegetation and open spaces worsens the situation by reducing natural shading and evaporation.

However, traditional urban practices in Central Asia historically addressed overheating through water-based cooling systems such as ariqs, qanats, and sardobas (Fathy, 1986; Makhmudov, 2010). These elements were used to distribute water across cities and create cooler outdoor spaces. Flowing water and open reservoirs helped reduce air temperatures through evaporative cooling, forming comfortable microclimates in streets, courtyards, and public areas. In addition, the presence of water improved humidity levels and supported vegetation growth, further enhancing thermal comfort.

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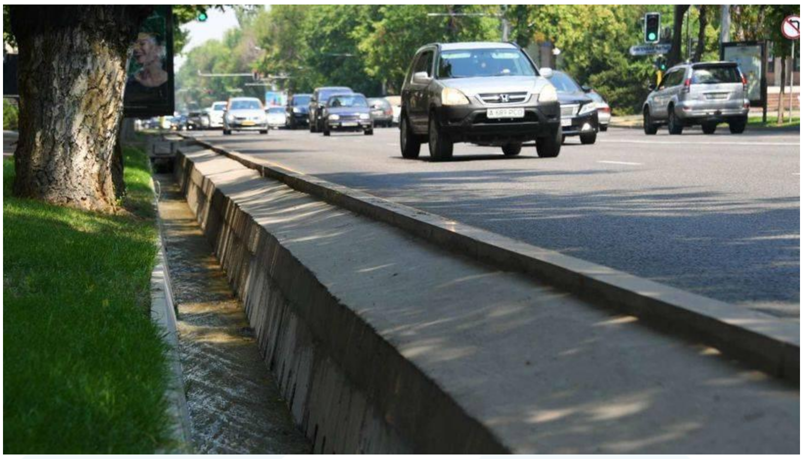

Figure 1. (An illustration of ariqs in Kazakhstan, Almaty (2019))

Today, many of these traditional systems have been replaced or neglected due to modern urban development. Reintroducing and adapting such water-based strategies in contemporary urban design could help reduce overheating and improve outdoor thermal comfort. By combining traditional knowledge with modern planning approaches, cities in hot climates can create more sustainable and climate-responsive urban environments.

Figure 2. (An illustration of Channel of the Qanats of Ghasabeh in Iran's Razavi Khorasan Province (2015)).

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Thermal Comfort in Buildings

In the context of indoor environmental quality, thermal comfort is an important aspect of human-centered design, as it influences occupants' health, comfort, and ability to use a space effectively. It refers to the level of satisfaction people feel with the thermal conditions of their environment. Traditional models of thermal comfort often focus on maintaining fixed indoor temperature ranges through mechanical systems. However, adaptive thermal comfort theory suggests that occupants can tolerate a wider range of temperatures when buildings are designed to respond to local climate conditions and allow user interaction.

Factors influencing thermal comfort can be divided into objective and subjective factors (Fanger, 1970; de Dear and Brager, 1998). Objective factors are related to the physical environment that do not depend on people, that are air temperature, radiant temperature, relative humidity, air velocity. Subjective factors depend on us, like clothing, metabolism. Related to clothing and material: white cloth reflects the heat, while black one absorbs.

In addition to these factors, it is crucial to consider individuals and electrical appliances (fridges, lamps, computers) influence to internal thermal comfort by generating the heat. Passive design strategies aim to address these factors through architectural solutions, such as building form, materials, and natural ventilation, rather than relying on energy-intensive mechanical technologies.

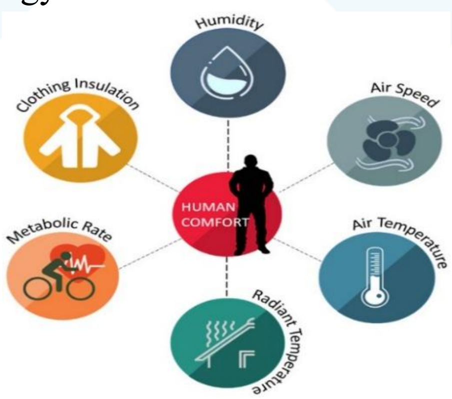

Figure 3. (An illustration of environmental and personal factors impacting on thermal comfort)

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Passive Design in Architecture

Passive design refers to architectural strategies that use natural environmental conditions to create comfortable indoor spaces (Olgyay, 1963; Givoni, 1998). Unlike active systems, passive solutions do not depend on mechanical equipment such as air conditioning or heating systems. Instead, they rely on building orientation by considering summer and winter solstice (June 22 and December 22), natural ventilation, shading, using double skin facade, suitable materials and windows, and the use of landscape elements to control indoor temperature.

Previous studies show that passive design strategies work best when they are considered at the early stages of the design process (Szokolay, 2014). In urban environments, where high density and climatic challenges are more pronounced, passive design requires coordination between individual buildings and the surrounding urban context. Decisions made at both building and city scales can influence the effectiveness of passive cooling strategies.

Methodology

This study uses a qualitative research approach based on a review of academic literature, architectural case studies, and design guidelines related to passive design and thermal comfort. The research focuses on analyzing existing studies to identify passive strategies that can be applied to urban buildings.

Instead of using numerical simulations or field experiments, the paper emphasizes conceptual analysis and design-based discussion. This approach allows for a clearer understanding of architectural principles and how they can be adapted to different urban and climatic conditions.

Passive Design Strategies for Thermal Comfort:

Passive design is an architectural approach that uses the building’s shape, windows, and materials to keep comfort. Instead of relying on machines like air conditioners or heaters (active design), a passive building "works" on its own by

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using the sun, wind, and shade. The key parameters that contribute to thermal comfort are outlined below.

1. Building Orientation and Urban Layout

Building orientation plays an important role in controlling solar heat gain in buildings. When designing a building orientation, four dates need to be taken into account: March 21, June 22, September 21 and December 22. It is crucial due to a well-oriented building can reduce direct exposure to strong sunlight while still allowing sufficient natural daylight, minimizing overheating. In hot climates, reducing east and west facing facades is especially important, as these sides receive low-angle sunlight that is difficult to block.

At the urban scale, street orientation and the distance between buildings affect airflow and shading. Even in compact cities, thoughtful spacing and variations in building height can improve natural ventilation and help reduce heat buildup in urban areas.

2. Natural Ventilation Strategies

Natural ventilation is one of the most effective passive methods for reducing indoor overheating (Givoni, 1998). Cross-ventilation occurs when air flows through a building from fenestration (openings like window, door and skylight) on opposite sides, helping to remove warm air from interior spaces. Stack ventilation uses vertical air movement, where warm air rises and exits through higher openings, drawing cooler air inside.

The size, position, and ability to open windows are key factors in successful natural ventilation. In dense urban environments, designers must also consider issues such as noise, air pollution, and privacy when applying ventilation strategies. Selecting the right window helps reducing these kinds of problems. R-value (thermal resistance), U-value (rate of heat transfer), SHGC (Solar Heat

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Gain Coefficient) and Visible transmittance are parameters that need to be considered when choosing windows.

3. Shading and Solar Control

Shading is essential for reducing direct solar radiation and limiting heat gain inside buildings. External shading devices, including overhangs, louvers, and screens, are particularly effective because they block sunlight before it reaches windows and walls.

In urban buildings, shading can be integrated into facades, balconies, and shared outdoor spaces. Vegetation-based shading, such as trees and green facades, provides additional cooling by lowering air temperatures through evapotranspiration.

4. Thermal Mass and Material Selection

Materials with high thermal mass, such as concrete, brick, and stone, are able to absorb heat during the day and release it during cooler nighttime hours (Szokolay, 2014; Fathy, 1986). This process slows down indoor temperature changes and helps reduce peak heat levels.

Thermal mass works most effectively when combined with night-time ventilation, especially in climates with large temperature differences between day and night. In Central Asia, particularly in Uzbekistan, traditional buildings have long used adobe (mud brick) as a construction material. Adobe has high thermal mass and allows buildings to remain cool during the day and warm at night. This traditional approach demonstrates how local materials, when adapted to the climate, can support thermal comfort without the use of mechanical cooling systems. Therefore, material selection should be closely related to local climatic conditions.

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5. Vegetation and Microclimate

Vegetation plays an important role in reducing overheating at both the building and urban scales. Green roofs, green walls, and courtyard gardens help cool buildings by shading surfaces and increasing evaporation.

In dense urban areas, vegetation improves local microclimates and outdoor comfort, which also influences indoor thermal conditions. Proper placement of greenery can reduce surface temperatures and create more comfortable living environments.

6. Insulation

Insulation plays a crucial role in passive design by reducing unwanted heat transfer between indoor and outdoor environments. There are a lot of types of insulation materials: fiberglass, denim, cellulose, natural, mineral insulations. Proper thermal insulation limits heat gain during hot periods and helps maintain stable indoor temperatures. As a result, buildings remain cooler during the day and experience less overheating.

In hot climates, insulation is especially important for roofs and external walls, which are highly exposed to solar radiation. When combined with appropriate shading and ventilation strategies, insulation improves the overall performance of the building envelope and reduces the need for mechanical cooling. Therefore, effective insulation should be considered as an essential passive design strategy in climate-responsive architecture.

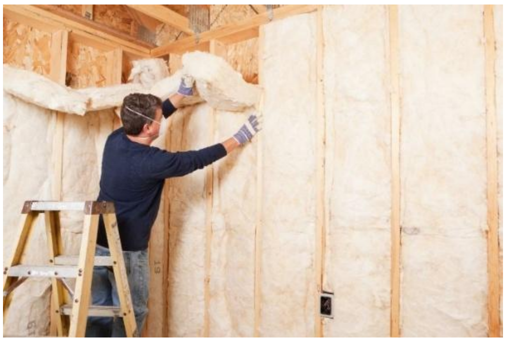

Figure 4. (An illustration of a man installing fiberglass insulation)

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Discussion

The analysis shows that no single passive strategy can fully solve the problem of overheating in urban buildings. Instead, thermal comfort is best achieved by combining several strategies based on specific climatic and urban conditions. Building orientation, ventilation, shading, material selection, and vegetation need to function together as part of an integrated design approach.

One of the main challenges in urban environments is applying passive design within limited space and dealing with issues such as noise and air pollution. However, research suggests that well-designed passive solutions can significantly reduce the need for mechanical cooling systems.

Passive design strategies are most effective when considered at the early stages of the design process. Although existing buildings can be retrofitted, this approach is often more complex and less efficient. For this reason, urban planning policies and building regulations play an important role in supporting climate-responsive architecture (Olgyay, 1963; Givoni, 1998).

Conclusion

With ongoing urbanization, overheating in urban buildings has become a major challenge for sustainable development. This study demonstrates that passive design strategies provide an effective and environmentally responsible way to improve thermal comfort without relying on mechanical cooling systems.

By improving building orientation, encouraging natural ventilation, using effective shading, selecting appropriate materials, and integrating vegetation, architects can reduce indoor overheating and enhance occupant comfort. These strategies also help lower energy consumption and contribute to healthier and more resilient urban environments.

The findings emphasize the importance of climate-sensitive design and the integration of passive strategies at both building and urban scales. Future research may focus on empirical studies and region-specific applications of passive design

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principles. Overall, passive design represents an important pathway toward sustainable architecture in rapidly urbanizing cities.

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