

Climate-Resilient Buildings in the Arab Anthropocene



Heat Risk and Low-Carbon Design

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Introduction

The Anthropocene describes a historical phase in which human activity has become a dominant force shaping the Earth system. Buildings and cities play a central role in this transformation because they concentrate energy use, materials, and human activity. Globally, the building sector accounts for a large share of energy consumption and carbon emissions while also providing the environments where societies experience climate risks such as extreme heat, floods, and air pollution (IPCC 2023; UNEP 2024). In this chapter, the term *carbon* is used as a shorthand for greenhouse gas (GHG) emissions expressed in carbon dioxide

equivalent (CO₂e), the standard metric used in building life-cycle assessment and climate policy.

The Arab region occupies a distinctive position within this global transformation. Extending from Mauritania and Morocco in the west to Oman and the Gulf states in the east, and from the Mediterranean basin to the Horn of Africa and the Comoros islands, the region encompasses 22 countries and highly diverse climatic conditions. These range from hyperarid deserts and Mediterranean climates to humid coastal environments, tropical islands, and mountain climates (WMO 2025). Mauritania experiences extreme Saharan heat and water scarcity, Somalia faces recurrent drought and fragile infrastructure, and the Comoros islands are exposed to humid tropical climates and cyclonic storms. Mountain environments such as the Moroccan Atlas, Abha in Saudi Arabia, and Saint Catherine in Egypt experience large seasonal temperature variations that require both cooling and heating strategies. This climatic diversity demonstrates that building design across the Arab region cannot rely on a single hot-desert model but must adapt to multiple environmental contexts.

Despite these climatic differences, most countries across the region share a structural characteristic: cooling-dominated energy demand combined with increasing climate vulnerability (Matallah et al. 2025). Rising temperatures, more frequent heat waves, and prolonged droughts are already affecting cities and rural areas across the region (IPCC 2023; WMO

2025). Urbanization further amplifies these effects. Large metropolitan areas such as Cairo, Baghdad, Casablanca, and Riyadh experience strong urban heat island effects driven by dense construction, limited vegetation, and extensive paved surfaces. Urban overheating increases nighttime temperatures and reduces opportunities for passive cooling, exposing residents to prolonged heat stress (Kousis and Santamouris 2025).

Socioeconomic disparities strongly influence exposure to these climate risks. Oil-rich Gulf countries have invested heavily in infrastructure and mechanical cooling technologies, including large-scale air-conditioning systems and district cooling networks. However, these developments also create extremely high electricity demand during the summer months (IEA 2025). In contrast, many households in North Africa, the Levant, Sudan, and Yemen live in buildings without reliable heating, cooling, or mechanical ventilation systems. Much of the residential building stock, therefore, operates in free-running mode, meaning indoor temperatures depend almost entirely on outdoor climate conditions and passive building characteristics (Attia 2025).

Environmental factors further complicate thermal resilience. Dust transport from the Sahara and Arabian deserts regularly affects air quality across North Africa and the Middle East. Large-scale dust events transport significant quantities of particulate matter across urban areas and can degrade indoor air quality in buildings that rely on natural ventilation (Goudie and Middleton 2006). Dust aerosols can also reduce solar radiation reaching urban surfaces, limiting winter solar heating and contributing to colder indoor conditions in poorly insulated buildings.

Rapid urban expansion across the region has also produced large construction sectors dominated by reinforced concrete and energy-intensive materials. In many cities, economic growth has translated primarily into construction activity, producing extensive “concrete landscapes” with high embodied carbon and limited climatic responsiveness. Imported architectural models, particularly highly glazed façades and sealed envelopes derived from temperate-climate

building standards, often increase solar heat gains and cooling demand rather than reducing them (Attia 2025; UNEP 2024).

Buildings, therefore, sit at the center of a dual challenge in the Arab Anthropocene. They must provide safe indoor environments during increasingly extreme heat while simultaneously reducing operational and embodied carbon emissions. Addressing this challenge requires moving beyond imported design paradigms toward regionally adapted approaches that integrate passive cooling strategies, adaptive comfort models, efficient cooling systems, and low-carbon construction practices. The following sections examine heat risk in the built environment, explore climate-resilient building design strategies, and discuss pathways toward low-carbon buildings and governance frameworks capable of supporting climate-responsive urban development.

Heat Risk in the Built Environment

Heat exposure has become one of the most critical climate-related risks affecting the built environment across the Arab region. Rising average temperatures, longer heat waves, and rapid urbanization increasingly expose populations to dangerous indoor and outdoor thermal conditions (IPCC 2023; WMO 2025). In many cities, the interaction between climate change and urban development patterns has intensified heat accumulation in buildings and streets, creating complex urban thermal environments.

Across much of the Middle East and North Africa, summer temperatures frequently exceed thresholds associated with human thermal stress. Urban heat island effects further amplify these conditions by increasing nighttime temperatures and reducing opportunities for passive cooling. Dense urban fabrics, dark construction materials, and limited vegetation contribute to heat storage in streets and buildings. In metropolitan areas such as Cairo, Baghdad, Kuwait City, and Riyadh, nighttime temperatures during heat waves often remain high enough to prevent buildings from releasing accumulated heat, exposing residents

to prolonged indoor overheating (Santamouris 2020).

Indoor overheating is therefore emerging as a major building-related hazard. A large share of the population in many Arab countries lives in housing that lacks reliable mechanical cooling systems or a continuous electricity supply. Outside the Gulf Cooperation Council countries, much of the residential building stock operates in free-running mode, meaning indoor temperatures depend primarily on outdoor climate conditions and passive building characteristics (Attia 2025). Buildings without adequate shading, insulation, or thermal mass may therefore experience indoor temperatures that exceed outdoor conditions during summer heat waves.

Housing conditions significantly shape exposure to heat risk across the Arab region. Rapid urbanization and persistent socioeconomic inequality have produced large segments of the population living in buildings that cannot maintain safe indoor temperatures. This condition is increasingly described in the literature as energy poverty, defined as the inability of households to secure adequate energy services required to maintain healthy indoor environments. In hot climates, this phenomenon often manifests as cooling poverty, where households lack access to affordable air-conditioning, reliable electricity, or thermally adequate housing (Attia et al. 2019). In the Middle East and North Africa, energy poverty is strongly correlated with income inequality and infrastructure gaps, particularly in North Africa, Yemen, and parts of the Levant, where electricity access and building quality remain uneven (Belaïd and Flambard 2023). Under these conditions, households exposed to extreme heat frequently rely on poorly insulated buildings operating in free-running mode, increasing vulnerability to indoor overheating and heat-related health risks. Without targeted policies addressing both housing quality and access to cooling energy services, rising temperatures are likely to deepen thermal inequality across the region (Belaïd and Flambard 2023).

Heat risk in the region is also closely linked to energy infrastructure. Cooling demand already accounts for a large share of electricity consumption in several Middle Eastern countries,

particularly during summer months. Air-conditioning systems dominate peak electricity demand in Gulf states, creating strong pressure on electricity infrastructure during extreme heat events (IEA 2025). As temperatures rise, cooling demand increases further, creating feedback loops in which electricity systems must expand to maintain indoor comfort while simultaneously increasing greenhouse gas emissions.

In contrast, many households in lower-income countries across the region cannot rely on energy-intensive cooling systems. In fragile contexts such as Yemen, Sudan, and parts of the Levant, electricity supply may be intermittent or unavailable for extended periods. Under these conditions, buildings themselves become the primary line of defense against extreme heat. However, inadequate building envelopes, poor shading, and limited ventilation capacity often reduce their ability to provide thermal protection.

Environmental conditions further complicate heat exposure. Dust storms originating from the Sahara and Arabian deserts frequently affect air quality across North Africa and the Middle East. Large-scale dust transport events can increase concentrations of particulate matter in urban environments and degrade outdoor air quality (Goudie and Middleton 2006). Buildings that rely heavily on natural ventilation may therefore introduce dust and pollutants into indoor spaces during these events, reducing indoor environmental quality and complicating passive cooling strategies.

Dust aerosols also influence urban thermal dynamics in less obvious ways. High atmospheric dust concentrations can reduce the amount of solar radiation reaching the urban surface. This phenomenon, sometimes described as atmospheric dimming, can reduce solar heat gains during winter months. In poorly insulated buildings, reduced solar radiation may contribute to colder indoor environments, producing localized urban cool island effects during winter in some cities. As a result, the built environment in the Arab region must address both extreme summer heat and seasonal cold exposure in certain climates.

Climate risks rarely occur in isolation. Dust storms, flash floods, and extreme rainfall events increasingly affect several countries across the

region. The catastrophic flooding that occurred in Libya in 2023 illustrated how fragile infrastructure and inadequate urban planning can transform climate hazards into large-scale disasters. Buildings in such contexts must therefore respond not only to heat but also to compound environmental risks that combine extreme weather with infrastructure vulnerability.

Urban morphology plays a critical role in shaping heat exposure across cities. Compact urban fabrics typical of historic Mediterranean and North African cities can provide shading and reduce solar exposure at street level. By contrast, rapidly expanding low-density urban developments common in parts of the Gulf often produce extensive paved surfaces and wide streets with limited shading. These patterns increase solar exposure and intensify daytime heat accumulation, raising cooling demand and worsening outdoor thermal conditions.

Understanding heat risk in the Arab-built environment, therefore, requires a systemic perspective linking climate dynamics, urban form, building performance, and socioeconomic inequality. Buildings are not merely passive recipients of climate stress but active components of urban energy and environmental systems. Poorly designed buildings amplify heat exposure and energy demand, while climate-responsive buildings can reduce heat vulnerability and improve public health outcomes.

Addressing heat risk across the region requires shifting from reactive cooling strategies toward integrated approaches that combine passive design, efficient cooling technologies, and climate-responsive urban planning. Such approaches must account for the region's climatic diversity, economic disparities, and infrastructure constraints (Eltinay and Egbu 2024). Recognizing these structural differences is essential for developing building solutions that improve thermal safety while supporting long-term decarbonization goals.

Climate-Resilient Building Design

Climate-resilient building design in the Arab region must respond to a combination of environmental stresses that differ from those typically addressed in temperate-climate building standards. Extreme heat, dust-laden atmospheres, rapid urbanization, and growing cooling demand shape the thermal performance requirements of buildings across the region. In many countries, buildings also operate under conditions of limited mechanical infrastructure, meaning that passive strategies and robust envelope design play a central role in maintaining indoor environmental quality. Climate-resilient buildings must therefore integrate passive cooling strategies, adaptive building envelopes, and efficient cooling technologies calibrated to local environmental conditions (WMO 2025).

At the same time, many contemporary buildings in the region replicate architectural and engineering approaches developed for heating-dominated climates. Glass curtain-wall façades, sealed envelopes, and uniform comfort standards have become common in rapidly developing cities despite their poor climatic suitability. These imported design logics frequently increase solar heat gains and cooling demand rather than reducing them. Climate-resilient design, therefore, requires both technological innovation and a critical reassessment of building models transferred from temperate regions.

Design Principles That Work Across Climates

Several design strategies consistently improve thermal resilience across the diverse climatic conditions of the Arab region.

Shading is the most effective measure for limiting solar heat gains. External shading devices such as arcades, deep balconies, screens, vegetation, and recessed façades significantly reduce direct solar radiation entering buildings. Because solar radiation is a primary driver of cooling demand in hot climates, shading strategies can reduce indoor temperatures and mechanical cooling loads substantially (Santamouris 2020).

Thermal mass provides another important mechanism for moderating indoor temperatures. Materials such as stone, adobe, brick, and concrete absorb heat during the day and release it during cooler nighttime hours, reducing temperature fluctuations inside buildings. In hot-arid environments with large diurnal temperature differences, thermal mass can significantly delay heat transfer into interior spaces and improve thermal stability.

Natural ventilation can further enhance thermal comfort by increasing air movement and removing accumulated heat. Cross-ventilation and stack ventilation systems have historically played an important role in vernacular architecture across the region. However, the effectiveness of natural ventilation in contemporary urban environments is strongly influenced by outdoor air quality conditions.

Dust storms originating from the Sahara and Arabian deserts regularly transport large quantities of particulate matter across North Africa and the Middle East (Goudie and Middleton 2006). Seasonal wind systems such as khamsin winds in Egypt and haboob storms across the Arabian Peninsula can significantly reduce outdoor air quality. Under these conditions, unrestricted natural ventilation may introduce particulate pollution into indoor environments. Climate-resilient buildings, therefore, require flexible ventilation strategies combining natural airflow with filtered mechanical ventilation when dust concentrations are high.

Urban morphology also strongly influences building thermal performance. Compact urban fabrics with narrow shaded streets can reduce solar exposure and improve outdoor thermal comfort. Historic cities across North Africa and the Levant illustrate how dense urban form can create shaded pedestrian environments that moderate urban heat accumulation. By contrast, low-density urban expansion characterized by wide streets and extensive paved surfaces increases solar exposure and intensifies urban heat island effects (UN-Habitat 2022).

Together, these strategies form the first layer of climate resilience by reducing heat gains before mechanical cooling becomes necessary.

Limitations of Imported Building Models

Despite the effectiveness of passive design strategies, many contemporary buildings across the Arab region replicate architectural models developed for fundamentally different climatic contexts. Highly glazed façades, for example, have become common in commercial developments across Gulf cities and parts of North Africa. While such façades may perform adequately in moderate climates, in hot desert environments, they dramatically increase solar heat gains and cooling demand.

Another widely adopted design approach involves highly insulated and tightly sealed building envelopes designed to maintain constant indoor temperatures. These strategies originate from building standards developed for heating-dominated climates. When transferred directly to hot environments without adequate solar protection, sealed envelopes can trap internal heat gains and increase cooling loads.

Comfort standards reinforce this mismatch. Many buildings across the region maintain indoor temperatures around 21–22 °C throughout the year, reflecting thermal comfort models developed primarily in temperate climates. However, research on adaptive thermal comfort indicates that occupants in warm climates often tolerate higher indoor temperatures when environmental conditions and behavioral adaptation are considered (Attia et al. 2019; Humphreys et al. 2015). Maintaining artificially low indoor temperatures, therefore, leads to systematic overcooling and unnecessary energy consumption.

Climate-resilient design requires recalibrating building standards, façade technologies, and comfort expectations to reflect regional climatic conditions rather than replicating models developed for colder climates.

Regional Tailoring of Climate-Resilient Design

Although common principles apply across the Arab region, design strategies must also respond to distinct climatic and socioeconomic conditions in different subregions.

Gulf Cooperation Council (GCC)

Countries such as the United Arab Emirates, Qatar, Kuwait, Bahrain, and Saudi Arabia experience some of the highest summer temperatures globally. Buildings in these environments rely heavily on mechanical cooling, making peak electricity demand management a major concern. Climate-resilient design, therefore, emphasizes shading-first urban design, reduction of solar heat gains, and efficient cooling systems. District cooling systems and thermal energy storage technologies are increasingly used to improve cooling efficiency and shift electricity demand away from peak periods (IEA 2025). At the urban scale, shaded pedestrian corridors, arcades, and landscape interventions can significantly improve outdoor thermal comfort.

Levant

Countries such as Lebanon, Jordan, Syria, and Palestine experience mixed climates combining hot summers with cooler winters, requiring space heating. Buildings must therefore respond to both cooling and heating seasons. Adaptive comfort strategies offer important opportunities in this context. Allowing indoor temperatures to vary seasonally rather than maintaining a fixed year-round set point can significantly reduce energy consumption while maintaining acceptable comfort levels.

Egypt

Large metropolitan areas such as Greater Cairo illustrate the challenges associated with dense urban fabrics, aging infrastructure, and informal housing. Many buildings lack effective solar protection, insulation, or ventilation pathways. Climate-resilient design strategies in this context prioritize low-cost retrofit measures such as external shading devices, reflective roof coatings, improved natural ventilation, and façade upgrades that reduce indoor overheating.

Sudan and Yemen

In fragile contexts with limited energy infrastructure, reliance on energy-intensive cooling technologies may be unrealistic. Climate-resilient building strategies, therefore, emphasize

passive-first approaches including thick walls, high thermal mass construction, deep shading, and controlled ventilation. Community-scale cooling spaces and shaded public areas can also provide important protection during extreme heat events.

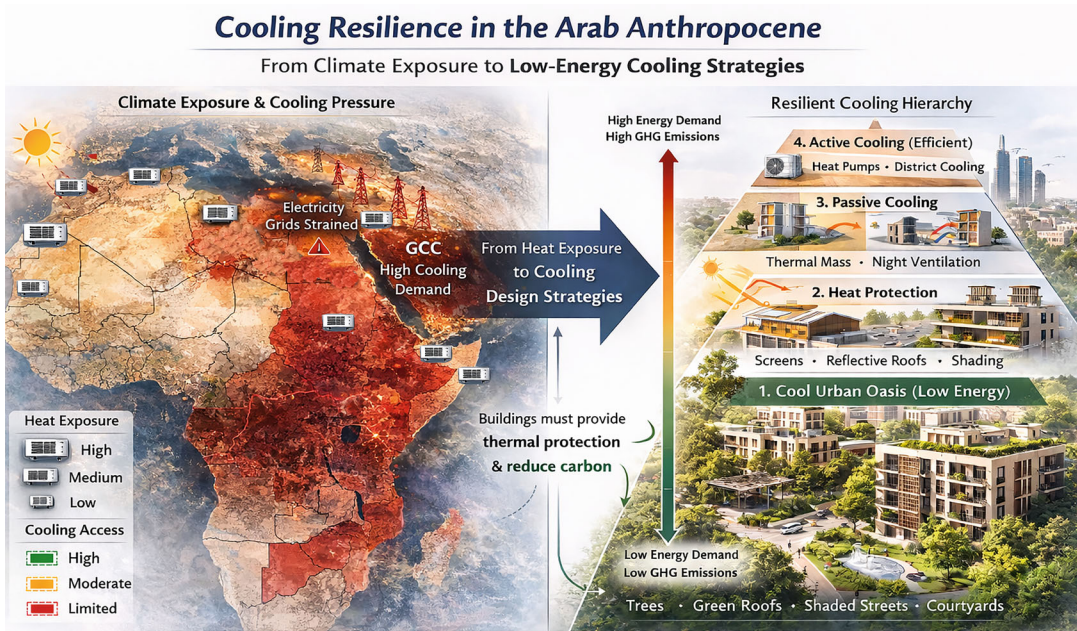
Maghreb

Countries such as Morocco, Algeria, and Tunisia combine Mediterranean coastal climates with inland desert conditions. Buildings in these regions benefit from a combination of thermal mass, shading, and natural ventilation strategies that moderate indoor temperatures while managing humidity. Increasing climate variability and extreme rainfall events also require integrating thermal resilience with flood risk management.

Toward a Resilient Cooling Hierarchy

Climate-resilient building design in the Arab Anthropocene requires a structured hierarchy of cooling strategies that prioritizes environmental and passive measures before energy-intensive technologies (see Fig. 1). This approach, often described as the Ladder of Cooling, organizes design interventions into four levels that progressively reduce cooling demand while minimizing energy use and greenhouse-gas emissions. The hierarchy reflects the climatic realities of the Arab region, where extreme heat exposure, rapid urbanization, and uneven access to reliable electricity require buildings to function simultaneously as thermal protection systems, energy infrastructures, and climate adaptation tools.

The first level of the hierarchy focuses on creating a cooling urban environment. Urban morphology strongly influences heat accumulation in cities across the Middle East and North Africa. Strategies at this level aim to reduce ambient temperatures through urban design rather than through building technologies. Vegetation, street trees, shaded public spaces, green roofs, and water elements can lower surface and air temperatures by reducing solar absorption and enhancing evapotranspiration. Compact urban forms with narrow shaded streets, arcades, and courtyard structures further limit solar exposure and improve outdoor thermal comfort. When



Climate-Resilient Buildings in the Arab Anthropocene, Fig. 1 Cooling resilience in the Arab Anthropocene: from climate exposure to cooling design strategies

integrated at the district scale, these measures can significantly reduce urban heat island intensity and lower cooling demand in surrounding buildings.

The second level aims to prevent heat gains before they enter the building envelope. Solar radiation is the dominant driver of cooling demand in hot climates, making solar protection one of the most effective design interventions. External shading systems such as overhangs, balconies, arcades, screens, and traditional shading elements such as *mashrabiya* can substantially reduce direct solar gains through windows and façades. Reflective roof materials and light-colored surfaces can also reduce heat absorption by increasing solar reflectance. In dense urban environments, façade articulation, recessed windows, and vegetated shading systems further reduce solar exposure. By limiting heat gains at the building boundary, these strategies reduce the cooling loads that mechanical systems must later address.

The third level consists of passive cooling strategies that regulate indoor temperatures using natural physical processes rather than energy-

intensive equipment. Thermal mass materials such as stone, adobe, brick, and concrete can absorb heat during the day and release it during cooler nighttime periods, stabilizing indoor temperatures. Night ventilation strategies can further enhance this effect by flushing accumulated heat from the building during evening hours. Cross-ventilation, stack ventilation, and wind-driven airflow systems historically used in vernacular architecture across the region can significantly improve indoor thermal comfort when outdoor air quality allows. These passive mechanisms are particularly important in contexts where electricity supply is unreliable or mechanical cooling is economically inaccessible.

The fourth level of the hierarchy involves environmentally efficient active cooling systems. Mechanical cooling technologies remain necessary during extreme heat events or in dense urban environments where passive strategies alone cannot maintain safe indoor conditions. However, within the cooling hierarchy, mechanical systems are deployed only after the previous levels have minimized heat gains and cooling loads. High-efficiency air-conditioning systems,

heat pumps, district cooling networks, and thermal energy storage technologies can provide reliable cooling while reducing electricity demand and associated emissions. When combined with passive design and renewable electricity generation, these systems can maintain thermal safety while supporting decarbonization objectives.

This hierarchical approach represents a significant shift from conventional building design practices in many rapidly developing cities across the region. Contemporary urban development often prioritizes mechanical cooling as the primary means of achieving thermal comfort, frequently resulting in highly glazed buildings with sealed envelopes that depend entirely on air-conditioning. In contrast, the cooling hierarchy emphasizes demand reduction before supply expansion, ensuring that buildings minimize heat gains and exploit natural cooling opportunities before relying on mechanical technologies.

Implementing this hierarchy also improves energy system resilience. During extreme heat events, electricity grids across the region experience substantial pressure due to peak cooling demand. Buildings designed according to the cooling hierarchy require less electricity to maintain safe indoor temperatures, reducing the risk of grid overloads and improving resilience during power outages. Passive and urban-scale cooling measures therefore function not only as architectural design strategies but also as infrastructure for climate adaptation and energy security.

In rapidly urbanizing regions facing increasing climate risks, integrating these four levels of cooling strategies provides a pathway toward buildings that simultaneously reduce heat exposure, lower energy demand, and limit greenhouse-gas emissions. Climate-responsive urban environments, solar heat protection, passive cooling, and efficient mechanical systems together form a coherent framework for designing buildings capable of operating safely within the climatic realities of the Arab Anthropocene.

Low-Carbon Buildings in Hot Climates

Low-carbon building strategies in the Arab region must address the structural characteristics of cooling-dominated climates. While global discussions of building decarbonization often focus on reducing heating demand, buildings across the Middle East and North Africa face the opposite challenge: extreme cooling demand. High summer temperatures, rapid urbanization, and expanding building stock are driving substantial growth in electricity consumption for cooling. As a result, reducing operational emissions associated with cooling systems and limiting embodied carbon in rapidly expanding construction sectors are central challenges for low-carbon building design in the region.

Operational Carbon in Cooling-Dominated Buildings

Operational carbon in buildings across the Arab region is largely determined by electricity consumption for cooling. Air-conditioning systems already represent one of the largest components of electricity demand in many countries, particularly during summer heat waves when cooling loads dominate peak electricity consumption (IEA 2025). In several Gulf countries, cooling demand alone accounts for a major share of peak electricity load.

Future projections indicate that cooling demand will continue to increase as urban populations grow and climate change intensifies heat exposure. Without improvements in building efficiency, this growth risks locking cities into energy-intensive infrastructure pathways in which expanding electricity generation capacity becomes necessary simply to maintain indoor thermal comfort.

Improving cooling efficiency, therefore, represents the most important operational carbon mitigation strategy in hot climates. Reducing solar heat gains through shading, reflective materials, and improved building envelopes can significantly decrease cooling loads. External shading devices, reflective roofs, and high-performance glazing reduce the amount of solar radiation

entering buildings and thereby reduce the electricity required for mechanical cooling.

High-efficiency air-conditioning systems and improved building controls can further reduce operational emissions. Advanced cooling technologies using variable-speed compressors, optimized refrigerants, and smart building controls improve system efficiency while maintaining acceptable thermal conditions.

However, focusing only on equipment efficiency is insufficient. The concept of net-zero energy buildings, widely promoted in temperate regions, requires reinterpretation in cooling-dominated climates. Conventional net-zero frameworks typically focus on balancing annual energy consumption with renewable energy production. In hot climates, however, the timing of electricity demand is equally important.

Cooling demand peaks during the hottest periods of the year when electricity systems already experience high stress. Buildings that achieve net-zero energy balances annually may still contribute to peak electricity demand during heat waves. For this reason, low-carbon buildings in hot climates must adopt a cooling-centric and peak-aware approach to energy design. Rather than focusing solely on annual energy balances, buildings should reduce peak cooling loads through passive design, shading, and thermal mass. This approach lowers electricity demand during extreme heat events and reduces pressure on the electricity infrastructure. Renewable energy systems can then complement these strategies by supplying electricity to meet the remaining cooling demand.

The Middle East and North Africa possess some of the highest solar irradiation levels globally, making photovoltaic systems particularly attractive for electricity generation. Solar energy can help offset cooling electricity demand and reduce dependence on fossil-fuel-based electricity generation. However, environmental conditions such as high temperatures and dust accumulation can reduce photovoltaic performance if systems are not properly maintained (Goudie and Middleton 2006). In desert environments, dust deposition on solar panels can significantly decrease electricity output, requiring regular

cleaning and maintenance to maintain efficiency. Low-carbon operational strategies must therefore combine passive cooling, efficient mechanical systems, renewable energy generation, and grid-responsive energy management.

Embodied Carbon and Rapid Urbanization

While operational energy consumption dominates discussions of building emissions, embodied carbon associated with construction materials represents a growing source of emissions in rapidly urbanizing regions. Over the past decades, the Arab world has experienced some of the fastest urban growth globally. This rapid urbanization has produced massive construction activity across major cities, resulting in large quantities of carbon-intensive building materials being used.

Urban expansion across the region is heavily dominated by reinforced concrete construction. Cement production is one of the most carbon-intensive industrial processes globally, and the widespread use of reinforced concrete significantly increases the embodied carbon footprint of buildings. Steel reinforcement, aluminum façades, and large quantities of glass further contribute to embodied emissions.

In rapidly expanding metropolitan areas, embodied carbon associated with new construction may represent a substantial share of the life-cycle emissions of buildings. Large urban developments composed primarily of reinforced concrete structures are often described as emerging “concrete landscapes,” where rapid urbanization translates directly into high material consumption and associated carbon emissions. Architectural design decisions also influence embodied carbon. High-rise buildings typically require larger structural systems and therefore greater quantities of concrete and steel. By contrast, climate-responsive buildings that integrate passive cooling strategies may allow for lighter structural systems and reduced material demand. Addressing embodied carbon, therefore, requires reconsidering both building materials and construction practices.

Circular Construction and Material Efficiency

Circular construction principles provide an important pathway for reducing embodied carbon in the building sector. Instead of relying exclusively on new materials, circular approaches aim to extend material life cycles through reuse, recycling, and resource efficiency.

Material efficiency is a central element of circular construction. Reducing unnecessary structural mass and optimizing building components can significantly lower embodied emissions. Designing buildings for durability and adaptability also extends building lifespans and reduces the need for demolition and reconstruction. Reuse of construction materials represents another important strategy. Salvaged steel components, recycled concrete aggregates, and reclaimed building materials can significantly reduce the carbon footprint of new construction projects. In regions where construction waste management remains limited, developing material recovery systems can produce substantial environmental benefits.

Local materials can also contribute to lower embodied carbon while improving climatic performance. Traditional construction materials such as stone, earth-based materials, and locally produced masonry often possess high thermal mass and lower embodied energy than industrial construction materials. When combined with modern construction techniques, such materials can contribute to both operational efficiency and reduced material emissions.

Circular construction also emphasizes design for disassembly, enabling building components to be recovered and reused at the end of their service life. This approach reduces construction waste and improves material efficiency across the building life cycle.

Integrating Operational and Embodied Carbon

Reducing carbon emissions from buildings in hot climates requires addressing both operational and embodied carbon simultaneously. Passive cooling strategies that reduce solar heat gains lower operational energy demand while also enabling simpler building systems with lower material requirements. Conversely, material choices that

improve thermal performance can reduce cooling demand during building operation.

The interaction between these two dimensions becomes particularly important in rapidly urbanizing regions. When large quantities of buildings are constructed within short time periods, embodied emissions from construction materials may represent a significant share of the overall carbon footprint of urban development. A life-cycle perspective is therefore essential for evaluating low-carbon building strategies. Rather than focusing solely on operational energy consumption, building design must consider emissions associated with material production, construction, building operation, and eventual demolition.

Integrating passive cooling strategies, efficient mechanical systems, renewable energy technologies, and circular material practices can significantly reduce the environmental footprint of the built environment in cooling-dominated climates.

The Heat–Carbon Trade-Off

Designing buildings for the Arab Anthropocene requires addressing a structural tension between thermal safety under extreme heat exposure and carbon mitigation in the building sector. In this chapter, heat refers to the combined effects of extreme outdoor temperatures, urban heat-island amplification, and indoor overheating in buildings. These three processes interact across much of the Arab region, especially in rapidly urbanizing cities where dense construction, low vegetation cover, and extensive paved surfaces intensify thermal stress. Protecting occupants from such heat exposure often requires cooling, yet cooling can increase electricity demand and greenhouse-gas emissions when energy systems remain carbon-intensive. This interaction defines the heat–carbon trade-off.

Across much of the Middle East and North Africa, cooling demand already dominates summer electricity consumption and often drives peak load conditions during heat waves. This creates a fundamental dilemma. Mechanical cooling provides the most reliable protection against indoor overheating and heat-related health risks, but it

can also lock buildings and cities into high-energy, high-emission trajectories. By contrast, passive and urban-scale cooling measures can substantially lower cooling demand and emissions, yet their protective capacity may be limited during prolonged extreme heat, hot nights, or dust events that constrain natural ventilation.

The trade-off is therefore not a simple opposition between “cooling” and “carbon.” It is a question of which type of cooling is used, at what scale, under what climatic stress, and for whom. In the Arab context, the first and often most overlooked level is urban oasis cooling. Vegetation, shaded streets, courtyard morphology, irrigated landscapes, and tree canopies can create localized cooler microclimates that reduce ambient temperatures before heat reaches the building envelope. This cooling effect, deeply rooted in traditional settlement logics across oasis towns, medinas, and courtyard-based urban fabrics, is especially relevant because it reduces demand rather than merely satisfying it. Urban oasis cooling does not replace building-scale solutions, but it can lower urban heat-island intensity and improve the effectiveness of the measures that follow (Santamouris 2020; UN-Habitat 2022).

The second level concerns heat exclusion at the building boundary. External shading, recessed openings, reflective roofs, screened façades, and climate-responsive envelopes can reduce solar gains substantially. In hot climates, this is often the most effective way to cut cooling demand without compromising comfort. The third level includes passive building cooling, such as thermal mass, night ventilation, and controlled airflow. These strategies are particularly valuable in buildings operating in free-running mode or in regions where the electricity supply is intermittent. The fourth level consists of environmentally efficient active cooling, including high-efficiency heat pumps, hybrid systems, and district cooling. These systems remain necessary in many contexts, but they should follow demand reduction rather than substitute for it.

To clarify these interactions, Table 1 proposes an analytical framework that compares cooling pathways not only by thermal performance and carbon implications but also by equity,

infrastructure dependence, and strategic value for future design scenarios.

This comparison shows that no single strategy can simultaneously maximize thermal protection, carbon reduction, and equity. Urban oasis cooling, solar protection, and passive cooling perform strongly in reducing demand and supporting equitable adaptation, but they may not always guarantee safe indoor conditions during the most severe heat events. Mechanical systems offer reliability, yet often at the price of higher emissions, greater grid stress, and stronger dependence on capital-intensive infrastructure. The design challenge is therefore not to choose one strategy, but to assemble them into a sequenced cooling logic in which low-carbon and low-energy measures form the foundation, and active cooling is used selectively and efficiently.

Equity is central to this synthesis. A strategy may be thermally effective and environmentally efficient but still fail socially if it assumes constant grid reliability, high capital investment, or access to advanced infrastructure. This is particularly important in fragile or infrastructure-constrained contexts such as Yemen, Sudan, or informal urban areas elsewhere in the region. In such environments, resilience cannot depend exclusively on active cooling. It must be built through combinations of shaded public space, cool refuges, urban oasis effects, passive survivability, and low-energy building design. By contrast, in affluent Gulf cities, district cooling and efficient mechanical systems may be technically viable, but even there, the question remains whether comfort is being achieved through optimized cooling or through overcooling.

This leads to a second major issue: Comfort standards are not neutral. Many buildings across the region still operate with fixed indoor set points around 21–22 °C, reflecting comfort models and operational habits derived largely from temperate-climate contexts. Yet adaptive thermal comfort research shows that occupants in warm climates can accept higher temperatures when buildings, clothing, air movement, and behavioral adaptation are considered (Attia et al. 2019). Overcooling, therefore, inflates electricity demand and emissions without necessarily improving

Climate-Resilient Buildings in the Arab Anthropocene, Table 1 Analytical synthesis of cooling pathways in the Arab Anthropocene

Cooling pathway	Primary scale	Thermal protection during extreme heat	Carbon implication	Equity and accessibility	Dependence on infrastructure	Strategic value for future scenarios
Urban oasis cooling: trees, shaded streets, courtyards, and vegetated public space	Urban/district	Low to moderate alone, but strong as a background cooling layer	Very low operational carbon; may also reduce building energy demand system-wide	High if integrated into public space and low-cost urban retrofit	Low to moderate, depending on irrigation and maintenance	Essential baseline for heat adaptation, urban livability, and demand reduction
Solar heat protection: external shading, screens, reflective roofs, and Deep balconies	Building envelope	Moderate to high when well designed	Low carbon with strong cooling-load reduction	High to moderate; suitable for retrofit and new build	Low	High-value no-regret strategy across most climates and income levels
Passive building cooling: thermal mass, night ventilation, and controlled airflow	Building	Moderate; context dependent and less reliable during hot nights or dust events	Very low to low	High in low-resource contexts if adapted to local climate and air quality	Low	Strong for resilient and low-energy design, especially where grid reliability is weak
Efficient hybrid cooling: passive-first design plus efficient heat pumps or mixed-mode operation	Building/block	High	Medium, but much lower than conventional AC when demand is first reduced	Moderate; depends on upfront cost and technical capacity	Moderate	Best transition pathway for medium-income urban contexts and retrofit programs
Conventional air-conditioning	Building	Very high	High, especially in carbon-intensive grids and overcooled buildings	Uneven; dependent on affordability and electricity access	High	Necessary in some extreme conditions, but weak as a stand-alone long-term strategy
District cooling and centralized systems	District/metropolitan	Very high in dense serviced areas	Medium to low per unit of cooling if efficiently managed, but infrastructure-intensive	Low to moderate; often restricted to high-investment developments	Very high	Suitable for selected dense urban zones, but limited transferability to fragile or dispersed contexts

satisfaction. The heat–carbon trade-off is not only about technology choice; it is also about the cultural and regulatory definition of comfort.

A final layer of complexity lies in infrastructure coupling. In several Gulf countries, cooling demand is intertwined with electricity generation, peak-load management, and water production through desalination. During extreme heat events, cities must often meet rising demand for both cooling and water simultaneously. This means that building-scale cooling decisions can no longer be treated in isolation from wider urban systems. The heat–carbon trade-off is therefore also a grid–water–urban form trade-off.

Addressing this challenge requires a **systems-based design approach**. The most robust pathway is to begin with urban oasis cooling and heat exclusion, then reduce residual loads through passive building design, and only afterward rely on efficient active systems sized for lower demand. This hierarchy improves thermal safety, limits emissions, reduces peak electricity stress, and expands the range of viable design options across unequal socioeconomic contexts. In cooling-dominated climates, decarbonization cannot be separated from thermal resilience. Buildings must function at once as **climate shelters, demand-management devices, and carbon mitigation systems**. Managing the heat–carbon trade-off is therefore essential for future design scenarios in the Arab Anthropocene.

Governance and Standards

The performance of buildings in the Arab region is shaped not only by architectural design and engineering solutions but also by governance structures, regulatory frameworks, and institutional capacity. Building codes, urban planning policies, and energy regulations determine how buildings are designed, constructed, and operated. However, governance systems across the Arab region vary widely in maturity, enforcement capacity, and climatic relevance. In many cases, building regulations have been adapted from international frameworks developed for fundamentally different climatic contexts. When such

standards are transferred without adaptation, they often fail to address cooling-dominated energy demand, urban heat island effects, and the socio-economic diversity of the region (WMO 2025).

Effective governance for climate-resilient buildings must therefore move beyond imported models and instead reflect regional climatic conditions, urban morphology, and infrastructure realities. The challenge is not merely technical but institutional: designing regulatory systems that simultaneously support thermal safety, energy efficiency, and equitable access to cooling.

Why Imported Standards Often Fail

Many building standards used in the Middle East and North Africa originate from regulatory frameworks developed in Europe or North America. These frameworks were primarily designed for heating-dominated climates, where the central objective of building regulation is to reduce winter heat loss. When transferred directly to hot climates, such standards may generate unintended outcomes.

For example, insulation strategies designed for cold climates are sometimes implemented without adequate solar protection measures. In cooling-dominated environments, this can increase internal heat accumulation and raise cooling demand rather than reduce it. Similarly, envelope designs emphasizing airtightness and sealed façades can limit natural ventilation opportunities in climates where air movement plays an important role in passive cooling.

Comfort models embedded in many international standards also reflect assumptions developed in mechanically conditioned buildings in temperate climates. These models often prescribe fixed indoor temperature targets around 21–22 °C. However, adaptive thermal comfort research demonstrates that occupants in warm climates can tolerate significantly higher indoor temperatures when behavioral and environmental adaptation are considered (Humphreys et al. 2015). Maintaining artificially low indoor temperatures, therefore, increases electricity consumption without necessarily improving thermal satisfaction.

Another critical challenge concerns implementation capacity. In several countries across the

region, building codes formally exist, but enforcement remains uneven. Rapid urban expansion, large informal housing sectors, and fragmented planning systems limit the ability of authorities to ensure compliance with building performance regulations. As a result, the actual thermal performance of buildings frequently diverges from design intentions.

These limitations illustrate that building standards cannot simply be transferred between climatic and institutional contexts without substantial adaptation.

Why Governance Must Differ Across Subregions

The Arab region encompasses wide variations in economic capacity, institutional strength, infrastructure reliability, and urban development patterns. Consequently, regulatory strategies that function effectively in one context may be unsuitable in another.

High-income Gulf countries such as the United Arab Emirates, Qatar, and Saudi Arabia have invested heavily in electricity infrastructure and building energy regulation. In these countries, cooling demand represents a dominant share of urban electricity consumption, particularly during extreme heat events. Governance priorities, therefore, focus on managing peak electricity demand, improving cooling efficiency, and integrating district cooling infrastructure.

In contrast, many countries in North Africa and the Levant face different challenges. Electricity supply may be less reliable, enforcement capacity may be limited, and a significant share of housing may exist in informal construction sectors. In such contexts, regulatory frameworks that rely heavily on complex certification systems or high-technology building solutions may prove difficult to implement effectively. Fragile contexts such as Yemen and Sudan face even greater constraints. In these environments, ensuring basic thermal safety becomes the primary governance objective. Regulatory strategies must therefore emphasize passive cooling measures, shading requirements, and climate-responsive urban planning rather than relying on advanced mechanical technologies.

A regional review of building energy policies highlights substantial variation in regulatory maturity and climate adaptation measures across Middle Eastern and North African countries (Carlucci 2024). This diversity demonstrates that governance frameworks must be differentiated rather than standardized.

Toward Climate-Responsive Governance

Developing governance systems capable of supporting climate-resilient buildings requires integrating several policy instruments.

First, climate zoning is essential. The Arab region includes multiple climatic environments ranging from Mediterranean coastal climates to hyperarid deserts and mountainous regions. Regulatory frameworks must therefore define performance requirements that reflect local climatic conditions rather than applying uniform national standards.

Second, minimum thermal safety standards should be incorporated into building codes. During extreme heat events, buildings must provide indoor environments that prevent dangerous overheating. Such standards may include requirements for shading, ventilation pathways, solar protection, and thermal mass.

Third, cooling access policies are increasingly recognized as an important element of climate adaptation. Reliable access to cooling during heat waves can significantly reduce heat-related mortality and improve public health outcomes. Policies supporting efficient cooling technologies, improved electricity reliability, and accessible cooling spaces can therefore strengthen urban resilience.

Fourth, urban oasis strategies should be integrated into urban planning regulations. Vegetation, shaded streets, and climate-responsive urban morphology reduce ambient temperatures and lower cooling demand at the city scale. Governance frameworks that incorporate urban greening, shading infrastructure, and public cooling spaces can therefore function as climate adaptation measures.

Finally, embodied carbon disclosure and life-cycle assessment should become part of building regulations. Rapid urbanization across the region

Climate-Resilient Buildings in the Arab Anthropocene, Table 2 Governance pathways for climate-resilient buildings across the Arab region

Regional context	Gulf Cooperation Council (GCC)	Levant	Egypt and large metropolitan regions	Maghreb	Fragile contexts (Sudan, Yemen)
Climate exposure	Extreme heat and cooling-dominated energy demand	Mixed cooling and heating climates	Dense urban heat island environments	Mediterranean and desert climate mix	Extreme heat combined with infrastructure fragility
Governance priority	Peak electricity demand management	Seasonal energy balance	Urban heat mitigation	Balanced thermal performance	Basic thermal safety
Cooling strategy emphasis	Efficient mechanical cooling and district cooling	Adaptive comfort and passive cooling	Solar protection, urban greening, and building retrofit	Passive cooling and climate-adapted architecture	Passive cooling and community cooling spaces
Institutional challenge	Managing energy demand growth and overcooling	Policy coordination across energy and housing sectors	Informal housing and enforcement capacity	Integrating climate adaptation with urban growth	Limited electricity infrastructure and institutional capacity
Strategic policy pathway	Integrate cooling hierarchy with renewable energy and urban shading	Climate-responsive building codes and retrofit programs	Urban oasis strategies and low-cost retrofit policies	Climate zoning and vernacular design integration	Low-energy cooling standards and humanitarian adaptation policies

has produced extensive construction activity dominated by carbon-intensive materials such as cement and steel. Policies encouraging material transparency, circular construction practices, and low-carbon materials can significantly reduce the environmental footprint of future urban development. To synthesize these governance challenges and opportunities, Table 2 compares regulatory priorities across different regional contexts.

Together, these governance approaches demonstrate that climate-resilient buildings depend not only on technological innovation but also on institutional frameworks capable of integrating climate science, urban planning, building design, and social equity. Rather than relying on imported standards developed for heating-dominated climates, governance systems in the Arab Anthropocene must reflect the region’s climatic diversity, infrastructure constraints, and socioeconomic realities. In this context, effective governance is not simply about improving building

energy efficiency. It is about shaping cities and buildings that can simultaneously reduce heat exposure, limit carbon emissions, and ensure equitable access to cooling in a rapidly warming region.

Conclusion

The Arab Anthropocene places the built environment at the center of two converging challenges: escalating heat exposure and rising energy demand in rapidly urbanizing cities. Buildings in the Middle East and North Africa must therefore function not only as shelters providing comfort but also as climate adaptation infrastructure and instruments for carbon mitigation. In cooling-dominated climates, electricity demand for air-conditioning already drives summer peak loads across much of the region, creating a trajectory

that risks locking cities into energy-intensive development pathways.

Addressing this challenge requires rethinking cooling as a hierarchical system rather than relying primarily on mechanical air-conditioning. Urban design strategies such as vegetation, shaded streets, and climate-responsive urban form can lower ambient temperatures. At the building scale, external shading, reflective roofs, and optimized façades reduce solar heat gains, while passive strategies such as thermal mass, natural ventilation, and night cooling moderate indoor temperatures. Efficient mechanical cooling should then serve as a final layer of protection during extreme heat events.

A central tension in this transition is the heat-carbon trade-off. Mechanical cooling improves thermal safety but increases electricity demand and associated emissions when powered by fossil-based grids. Passive and urban-scale strategies reduce carbon impacts but may offer limited protection during extreme heat. Effective design, therefore, requires combining passive architecture, efficient cooling technologies, and resilient energy systems to balance thermal safety and carbon mitigation.

Equity further complicates this challenge. Across parts of North Africa and fragile states, limited access to electricity and cooling creates forms of cooling or fuel poverty, where households cannot afford or reliably access thermal protection during heatwaves. Conversely, in wealthier Gulf cities, widespread access to cooling infrastructure can encourage excessive energy use and over-cooling. Climate-resilient building strategies must therefore protect vulnerable populations while avoiding unsustainable energy demand.

Governance frameworks are essential to enabling this transition. Climate-responsive building codes, retrofit policies, urban greening programs, and life-cycle carbon regulations can guide the built environment toward safer and lower-emission pathways. Importantly, regulatory approaches must reflect the realities of cooling-dominated climates rather than replicate standards designed for heating-oriented regions.

Ultimately, addressing heat risk in the Arab Anthropocene requires integrating passive design, efficient cooling technologies, urban climate

strategies, and adaptive governance. By reducing both heat exposure and energy demand, buildings can become key components of climate resilience while also contributing to global decarbonization efforts.

Cross-References

- [Circular Construction and Material Efficiency](#)
- [Climate Change Adaptation in the Middle East and North Africa](#)
- [Net-Zero Energy Buildings](#)
- [Urban Heat Island](#)

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