



# A New Pathway to Zero-Energy Cooling

Industry Insight Report on  
Electricity-Free Passive Radiative  
Cooling Technologies



# Table of Contents

|    |  |   |   |
|----|--|---|---|
| 01 | <b>Opening Chapter: Embarking on a New Era of Zero-Carbon Cooling</b> <ul style="list-style-type: none"> <li>1.1 Global Trends in Sustainable Development and New Cooling Demands</li> <li>1.2 Electricity-Free Passive Radiative Cooling: Reshaping Future Energy Use</li> </ul>  |    | <b>03</b><br><br>05<br><br>07               |
| 02 | <b>Technical Principles and Market Outlook</b> <ul style="list-style-type: none"> <li>2.1 Current Global Energy Consumption and Cooling Demand</li> <li>2.2 Introduction to the Technical Principles of Electricity-Free Passive Radiative Cooling</li> <li>2.3 Global and China Market Potential Outlook</li> <li>2.4 Energy Conservation and Emission Reduction Policies Driving Industry Growth</li> <li>2.5 Market Trends and Sustainable Investment Accelerating Industry Deployment</li> </ul> |   | <b>08</b><br><br>09<br>10<br>12<br>19<br>21 |
| 03 | <b>Product Innovation Highlights and Application Advantages</b> <ul style="list-style-type: none"> <li>3.1 Introduction and Advantage Analysis of Mainstream Products</li> <li>3.2 Panorama Demonstration of Application Scenarios</li> <li>3.3 Industry Case Studies</li> </ul>   |  | <b>22</b><br><br>23<br>25<br>27             |
| 04 | <b>Market Opportunities and Business Value Analysis</b> <ul style="list-style-type: none"> <li>4.1 Development Trends of Promotion Pathways and Cooperation Models</li> <li>4.2 Evolution Trends of Passive Cooling Technologies and Products</li> <li>4.3 Challenges and Recommended Responses</li> <li>4.4 Collaborative Initiatives and Ecosystem Co-Development Pathways</li> </ul>  |  | <b>35</b><br><br>36<br>38<br>39<br>41       |



# Foreword

Against the backdrop of global climate change and China's 'dual carbon' goals, the development of efficient and low-carbon cooling technologies has become increasingly important. Electricity-free passive radiative cooling, which leverages the physical mechanism of atmospheric window radiation, enables stable cooling without external energy input. This provides a low-carbon alternative for high-load sectors such as buildings, industry, and transportation, with promising application potential.

Today, leading enterprises in the industry are making continuous breakthroughs in materials development, system integration, and scenario-based deployment, thus laying the foundation for transitioning from laboratory validation to real-world engineering applications. This research report, prepared by KPMG, systematically reviews the technical principles, current applications, and future trends of electricity-free passive radiative cooling technologies, offering valuable insights for the industry's development.

Looking ahead, the industry should strengthen efforts in standardisation and pilot demonstration, and promote the integration of these technologies with green buildings, low-carbon industrial parks, and smart factories, to accelerate commercialisation. With improved collaboration across academia, industry, and research, electricity-free passive radiative cooling solutions are poised to play an increasingly important role in both 'source-side carbon reduction' and 'system-level efficiency enhancement,' injecting new momentum into urban regeneration and sustainable development.

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In the context of China's deepening "dual carbon" strategy, advancing green transformation in the cooling sector has become a critical challenge in both energy transition and urban governance. As an emerging thermal management solution, electricity-free passive radiative cooling offers a "zero-energy, low-maintenance" approach that serves as a viable alternative in buildings, transportation, and industrial applications, showing strong potential for sustainable development.

In recent years, with continued breakthroughs in materials and validation across practical scenarios, this technology is moving from scientific exploration to engineering deployment. Driven by favourable policy, rising investment, and growing end-user demand, the sector now has a solid foundation for scaling up.

This report integrates KPMG's insights in the fields of energy and sustainability, drawing on policy trends, market cases, and technology evolution paths to provide a systematic reference for stakeholders. Through this study, we hope to accelerate the adoption of cutting-edge green technologies and contribute to the development of a low-carbon, secure, and efficient energy future.

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# 01

## Opening Chapter: Embarking on a New Era of Zero-Carbon Cooling



Amid the deepening pursuit of the 'dual carbon' goals and global energy transition, the way humanity cools its living and working environments is undergoing a profound transformation. Statistics show that approximately 20% of global energy consumption is used for space cooling, and this figure continues to rise in hot regions and rapidly urbanising cities. Traditional active cooling systems, which rely heavily on electricity and refrigerants, are increasingly criticised for their structural inefficiencies—high energy consumption and significant carbon emissions. The search for greener, more efficient, and sustainable cooling solutions has become a pressing topic on the global energy and climate agenda.

Electricity-free passive radiative cooling (EPRC) offers a disruptive and nearly 'zero-energy, zero-emission' alternative. This technology leverages the physical mechanism of atmospheric window radiation—by emitting heat within specific infrared wavelengths directly into outer space, it achieves cooling without any external energy input. Its core value lies in breaking away from traditional energy exchange models, offering intrinsic energy-saving benefits, silent operation, and broad material compatibility. In recent years, advancements in nanomaterials and optical engineering have propelled this technology from the lab towards practical deployment, with its industrial foundation steadily maturing.

Emerging markets such as China are becoming global hubs of innovation in this field. Demonstration projects across various application scenarios—building rooftops, transportation infrastructure, outdoor energy storage, logistics warehousing, and even functional textiles—have begun to gain momentum. Some domestic companies have achieved notable breakthroughs in materials engineering, product integration, and system adaptation, providing scalable solutions for broader implementation. These pioneers are also playing a pivotal role in shaping industry norms, product standards, and cross-sector collaboration mechanisms.

In the broader wave of green transition, transformative technologies often arise from a renewed understanding and efficient harnessing of natural principles. Electricity-free passive radiative cooling, grounded in the logic of nature and aimed at sustainability, is such a frontier innovation. It not only reimagines how we meet global cooling demand, but also opens new possibilities for zero-carbon cities, industries, and lifestyles. Now is a crucial window of opportunity—to accelerate breakthroughs, build consensus, and guide the market. Together, we stand at the threshold of a new era of zero-carbon cooling.



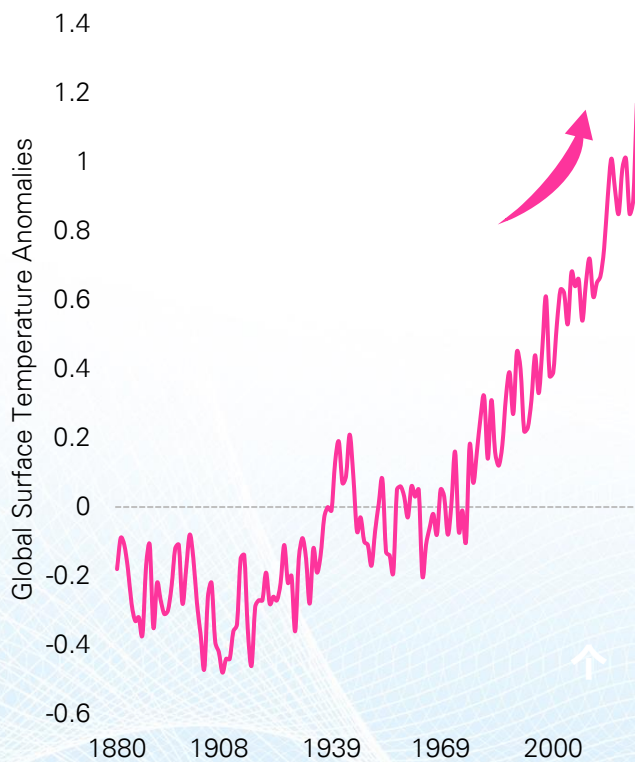


# 1.1

## Global Trends in Sustainable Development and New Cooling Demands

In recent years, the global sustainability agenda has deepened significantly, with energy transition, climate resilience, and environmental pollution control becoming shared priorities in multilateral cooperation and national strategies. The United Nations' 2030 Sustainable Development Goals (SDGs) explicitly call for 'access to affordable, reliable, sustainable and modern energy for all' (Goal 7) and urge 'urgent action to combat climate change and its impacts' (Goal 13). Within this global framework, sustainable cooling has increasingly emerged as a core issue, gaining strategic importance in areas such as energy security, public health, and urban governance.

### Rising Global Temperatures



Source: NASA

Over the past 50 years, the number of weather-related natural disasters has increased

**5** fold

From 2000 to 2019, an average of

**489,000** people

died from heatwaves annually

By 2030, extreme heat is expected to cause the loss of

**80,000,000**

full-time jobs globally

By 2050, total global economic output is projected to decline by

**4%~18%**

Source: i2COOL



Cooling has become a vital component in modern society for coping with heat, maintaining quality of life, and ensuring the safe storage and transportation of goods. According to estimates by the International Energy Agency (IEA), global demand for space cooling in buildings has more than tripled since 2000 and is expected to maintain high growth over the next 30 years. Accelerated urbanisation, more frequent extreme weather events, and rising living standards have made cooling one of the fastest-growing energy consumption sectors in emerging economies. Especially under the impact of global warming, cooling is no longer merely a 'comfort' service — it now serves critical social functions related to health, food security, and climate resilience.

However, the sustained growth in demand has come with significant energy and environmental costs. Traditional cooling systems are heavily reliant on electricity and often use refrigerants with high global warming potential, such as CFCs, Halons, and CCl<sub>4</sub>. These systems create multiple layers of pressure — in energy consumption, carbon emissions, and ozone depletion. It is estimated that cooling systems, through both direct and indirect emissions, account for nearly 10% of global greenhouse gas emissions. Without effective alternatives, cooling could become one of the major challenges to achieving global temperature control goals in the future.

### Pain Points of Traditional Cooling Solutions



#### High CO<sub>2</sub> Emissions

According to IEA, between 1990 and 2022, CO<sub>2</sub> emissions from air conditioning have nearly increased **3fold**



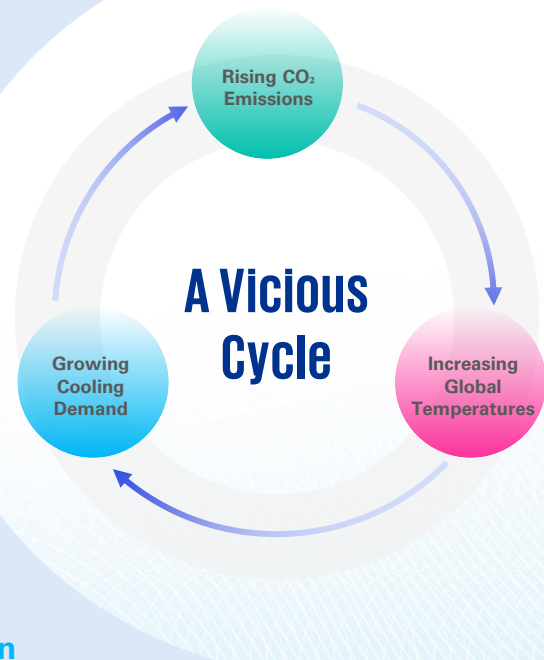
#### High Energy Consumption

To meet rising demand, energy use for global air conditioning is expected to grow from 850 GW in 2016 to 3,350 GW by 2050, increasing **395%**



#### Heavy Economic Burden

In many regions, spending on traditional cooling already accounts for 5%–15% of median household income. To accommodate growing cooling needs, the required investment in global power generation capacity could reach **USD 1.7 trillion**



This growing challenge is pushing governments, industry bodies, and technology firms to explore a new generation of green cooling solutions, focusing on four innovation pathways: energy efficiency, refrigerant replacement, system innovation, and passive cooling. In buildings, transport, industry, and agriculture, there is a growing interest in cooling methods that are 'low-carbon, safe, and energy-free.' International organisations such as the World Bank and UNEP have begun to support passive cooling technologies based on natural mechanisms, recognising them as priorities within green infrastructure and climate adaptation agendas.

Against this backdrop, electricity-free passive radiative cooling is emerging as a promising frontier technology, offering strong energy savings, environmental compatibility, and wide application potential. Its features — no electricity use, zero emissions — make it ideal for addressing the urban heat island effect in Global South cities, rural electricity shortages, and heat risks in climate-vulnerable areas. Whether this technology can scale from small pilots to large-scale deployment will directly influence the resilience of global energy systems and the pathway to achieving sustainable development goals.



## 1.2

## Electricity-Free Passive Radiative Cooling: Reshaping Future Energy Use



The future of energy systems hinges not only on how energy is obtained, but more critically on how it is used. While breakthroughs in clean power generation, smart distribution, and flexible storage have reshaped the energy supply side, a fundamental transformation in end-use consumption is now emerging as a cornerstone of low-carbon energy systems. In sectors like cooling—characterised by rigid, electricity-intensive growth—there is a pressing need for solutions that fundamentally differ from the traditional ‘input–conversion–output’ paradigm.

The emergence of electricity-free passive radiative cooling exemplifies this shift in energy-use philosophy. Unlike conventional cooling technologies that rely on mechanical and electrical systems (e.g., compressors, fans, refrigerant circuits), EPRC enables thermal regulation by precisely controlling radiative heat transfer through functional materials. It eliminates the dependency on external power sources and significantly simplifies the system architecture, reframing cooling as an environment-adaptive function rather than an energy-driven process. This change is profound. On one hand, it challenges the entrenched assumption that cooling must entail energy consumption, rendering the notion of ‘cooling without energy use’ technically viable. On the other hand, it decouples thermal regulation from energy infrastructure, offering novel solutions for urban operations, edge infrastructure, and climate resilience.

In urban areas suffering from intense heat island effects, this technology can be integrated into green building envelopes for continuous passive heat dissipation. In off-grid rural or remote regions, it can serve as an essential solution for maintaining material storage and human comfort. In special-use scenarios such as space exploration and marine-based floating platforms, its value is even more irreplaceable. Furthermore, the scalability of EPRC adds to its appeal. Since its core components are based on functional films and engineered material systems, it supports modularisation, composite integration, and flexible deployment. It can be applied as a standalone surface layer or embedded into rooftops, textiles, vehicle bodies, or equipment surfaces to create passive cooling interfaces. With ongoing advances in nanomaterials, vacuum coating, and spectral engineering, future EPRC materials are expected to become lighter, more powerful, and highly adaptable. Its broad-spectrum performance and cross-scenario applicability pave the way for cooling to evolve from ‘equipment dependence’ to ‘material intelligence’.

From a theoretical perspective, EPRC represents a revival of a ‘nature-synergistic view of energy’. It leverages the universe as a thermal sink, the atmospheric transparency window as a conduit, and engineered materials as a medium to enable the most direct, efficient thermal interaction between humans and their ambient environment. Within this simplicity lies profound energy significance and immense industrial potential.

Today, a growing number of policymakers, urban planners, and green tech innovators are turning their attention to this emerging technology, actively advancing its commercialisation. In China, several globally competitive materials technology companies have already validated their technical pathways and launched engineering-ready product lines, contributing to demonstration projects and accelerating the shift from concept validation to scaled deployment.

Looking ahead, as energy use transitions from ‘consumptive’ to ‘synergistic’, electricity-free passive radiative cooling will play a transformative role across buildings, industry, transportation, and civil life. It stands poised to redefine energy demand structures and emerge as a key enabler in the global pursuit of carbon neutrality.



# 02

## Technical Principles and Market Outlook

As a cutting-edge cooling solution characterised by ultra-low energy use and strong environmental friendliness, electricity-free passive radiative cooling is gaining increasing global attention. Under the dual pressure of 'enhancing energy efficiency' and 'reducing carbon emissions', the cooling sector urgently requires alternatives that break away from its dependence on electricity and chemical refrigerants. EPRC, based on the principle of natural thermal radiation, offers a fundamentally new path for this transformation.

This chapter systematically explores the technological logic and core components of electricity-free passive radiative cooling. It begins by reviewing the global trends in cooling-related energy consumption and the sector's challenges in meeting carbon peaking and carbon neutrality targets. It then introduces the operating mechanism and material characteristics of electricity-free passive radiative cooling, and analyzes the key driving forces behind its transition from laboratory research to commercial application—within the context of current policy frameworks and broader green transition trends. By presenting the technology principles, policy support, and market dynamics together, this chapter lays a solid foundation for understanding the next phase of product evolution, typical application models, and leading industry practices.

At present, a number of forward-looking technology companies with strong R&D capabilities are advancing this technology towards large-scale application by optimising material systems, overcoming industrialisation process bottlenecks, and innovating system integration. Looking ahead, under the combined influence of supportive national policies, growing market demand, and accelerated demonstration projects, electricity-free passive radiative cooling is expected to become a vital part of the global green cooling system, injecting long-term momentum into the development of a low-carbon society.

## 2.1 Current Global Energy Consumption and Cooling Demand

As urbanisation accelerates and global temperatures rise, cooling has become one of the fastest-growing end-use energy consumption sectors. From residential air conditioning and commercial buildings to industrial cold chains and digital infrastructure, the penetration of cooling systems is increasing rapidly, along with their associated energy consumption. According to the International Energy Agency (IEA), around 20% of global building energy consumption in 2022 was used for cooling—a proportion that continues to rise. By 2050, electricity demand for building cooling is projected to double, making it a primary driver of electricity load growth.

This trend is especially pronounced in emerging markets. In tropical and subtropical regions, where high temperatures are persistent year-round, the dependence on indoor cooling significantly exceeds the global average. Emerging economies such as China, India, Southeast Asia, and the Middle East are experiencing rapidly rising household incomes and urbanisation, which in turn are driving the widespread adoption of air conditioning in both residential and commercial buildings—creating substantial new cooling demand. In China, for example, total electricity consumption for building cooling exceeded 700 billion kilowatt-hours in 2020, accounting for nearly 30% of total building power use. In digital infrastructure, such as data centres, cooling systems now account for over 40% of total operating energy consumption.





In addition to electricity-related pressure, cooling also presents complex environmental challenges. Traditional cooling systems heavily rely on refrigerants such as HFCs (hydrofluorocarbons), which possess extremely high Global Warming Potentials (GWP)—hundreds to thousands of times that of carbon dioxide. While many countries have initiated refrigerant replacement programmes under international frameworks such as the Kigali Amendment, in the short term, these efforts are still constrained by immature alternatives, high costs, and the absence of adequate safety standards—falling far short of solving the dual challenge of ‘high energy consumption + high emissions’.

The timing of cooling demand often overlaps with grid peak loads. This significantly increases the operational risk of urban power systems. Under increasingly frequent extreme weather conditions, this issue has become even more prominent. For example, during the 2022 heatwaves in southern China, electricity loads in several cities approached critical thresholds, forcing some industrial parks to implement power rationing and staggered operations—highlighting the heavy burden cooling loads place on grid security and resilience.

As the world accelerates its transition towards low-carbon energy systems, the ‘decoupling’ of cooling from electricity becomes urgent. On one hand, it is essential to continue improving system efficiency—enhancing compressor performance, heat exchange structures, and control algorithms. On the other hand, there is an urgent need for entirely new technological approaches that depart from traditional electricity-driven paradigms—realising ‘cooling without power consumption’ and ‘temperature reduction without carbon emissions’.

Against this backdrop, electricity-free passive radiative cooling has garnered growing attention. As a power-independent, highly eco-friendly cooling solution, it offers not only zero power consumption during operation but also ultra-low life-cycle energy demand due to its ‘material-as-function’ nature. This makes it highly compatible with green buildings, distributed energy systems, and off-grid applications—emerging as a critical breakthrough in addressing both rising cooling demand and decarbonisation pressure.

## 2.2 Introduction to the Technical Principles of Electricity-Free Passive Radiative Cooling

Electricity-free passive radiative cooling is an innovative technology that utilises natural thermal radiation to continuously lower temperatures without consuming electricity. Its fundamental mechanism is based on the energy exchange between the Earth and outer space—particularly within the 8–13  $\mu\text{m}$  atmospheric transparency window, through which terrestrial objects can emit heat directly into the absolute-zero environment of space via mid-infrared radiation. This wavelength range is highly transparent to infrared radiation, allowing heat to ‘escape the atmosphere’ and achieve a cooling effect.

While traditional radiative cooling phenomena occur naturally—such as surface dew formation on summer nights—achieving similar cooling under direct sunlight requires overcoming two technical challenges:

- First, maximising solar reflectance to avoid heat absorption;
- Second, enhancing radiative emissivity within the atmospheric window to improve cooling performance.

Modern radiative cooling technologies hinge on advanced material designs and spectral control. Typical solutions utilise multilayer films, dielectric micro/nano-structures, or metal–dielectric composites. By precisely adjusting the thickness and interfacial characteristics of different layers, these materials achieve:

- Extremely high solar reflectance ( $R > 0.95$ ) across UV, visible, and near-infrared wavelengths;
- Strong mid- and far-infrared emissivity ( $\epsilon > 0.90$ ) within the atmospheric window.

This selective spectral response enables significant net cooling even under intense solar radiation. In real-world tests, the temperature of materials incorporating electricity-free passive radiative cooling has been shown to drop by 5–15°C compared to identical scenarios without the technology - delivering reliable, energy-free cooling across applications in architecture, transportation, energy storage, and more.

The evolution of this technology primarily unfolds along three directions:



#### Material system innovation:

From early oxide coatings to polymer composite films, metallic reflective layers, and photonic crystal structures, material systems have become increasingly diverse. Some leading enterprises have achieved continuous coating on flexible substrates or large-area deposition, overcoming limitations in application size and form.



#### Breakthroughs in fabrication processes:

From lab-scale manual coating to industrial-scale roll-to-roll coating and plasma-enhanced chemical vapour deposition (PECVD), the technology has significantly reduced costs while enhancing durability and weather resistance.



#### Expansion of system integration pathways:

Material functions have extended from simple 'surface cooling' to integration with building façades, rooftops, equipment enclosures, and wearable systems, forming new surface-interface material systems with combined cooling, insulation, and humidity control effects.

Particularly noteworthy is that in China, some materials technology enterprises are advancing this technology towards multi-scenario systematisation, such as deeply integrating electricity-free passive radiative cooling with building envelopes, vehicle-mounted cooling, battery thermal management, and other concrete application carriers, forming complete solution packages. This trend marks the transition of the industry from a 'materials-based' technological phase into a new stage of 'application-oriented, system-driven' engineering transformation.

In essence, electricity-free passive radiative cooling is a natural energy regulation technology that enables thermal adjustment without external energy input, embodying the shift in future energy usage from 'acquiring more' to 'using better'. Its energy-efficiency logic, system flexibility, and environmentally friendly attributes offer significant comparative advantages under the accelerating green transition and the diversification of terminal energy usage.





## 2.3

## Global and China Market Potential Outlook

Cooling is rapidly becoming one of the fastest-growing terminal energy consumption sectors in the global energy structure. According to projections by the International Energy Agency (IEA), by 2050, global electricity demand for building cooling will double compared to the current level, accounting for over 16% of total electricity consumption. This trend is driven by multiple structural factors, including continued urbanisation, increasingly frequent extreme heat events, and rising living standards, all of which contribute to the expansion of cooling loads. However, the high energy consumption, significant carbon emissions, and environmental controversies surrounding refrigerants in traditional cooling technologies reveal their fundamental limitations in meeting long-term cooling demands.

Take buildings as an example: over 40% of global building energy consumption is currently related to indoor cooling systems. In tropical and subtropical regions, cooling load has even become the dominant electricity use in buildings. In China, policies promoting green buildings, near-zero-energy buildings, and urban regeneration continue to advance. According to the Ministry of Housing and Urban-Rural Development, China's total urban building floor area has exceeded 68 billion square metres, with annual new construction still maintaining a scale of over 1 billion square metres. Among these, newly constructed public buildings and commercial-industrial parks alone contribute tens of millions of square metres annually that are potentially adaptable to passive cooling technologies. Meanwhile, the demand for outdoor high-heat load management in sectors such as new energy facilities, energy storage devices, power base stations, and cold chain systems is also rapidly emerging.

Against this backdrop, electricity-free passive radiative cooling technology demonstrates broad market development potential. On one hand, its integrability into building envelopes, equipment casings, and material interfaces expands its engineering application scope in the dimension of 'green materials – functional systems'. On the other hand, with the maturation of commercialisation pathways, it is evolving from single-purpose applications into comprehensive thermal management solutions, indicating strong platform-level penetration capability.

According to estimates, in China's building and industrial thermal management markets, assuming an annual addition of 200 million square metres of adaptable surface area and an energy-saving potential of approximately 20 kWh/year per square metre, the power-saving potential could reach 4 billion kWh, equivalent to over 3 million tonnes of CO<sub>2</sub>-equivalent emissions reduction. If temperature control needs in industrial tanks, communication equipment, and energy storage systems are also considered, the theoretical annual market size could reach several billion RMB, with a projected compound annual growth rate exceeding 20% over the next 3 to 5 years.

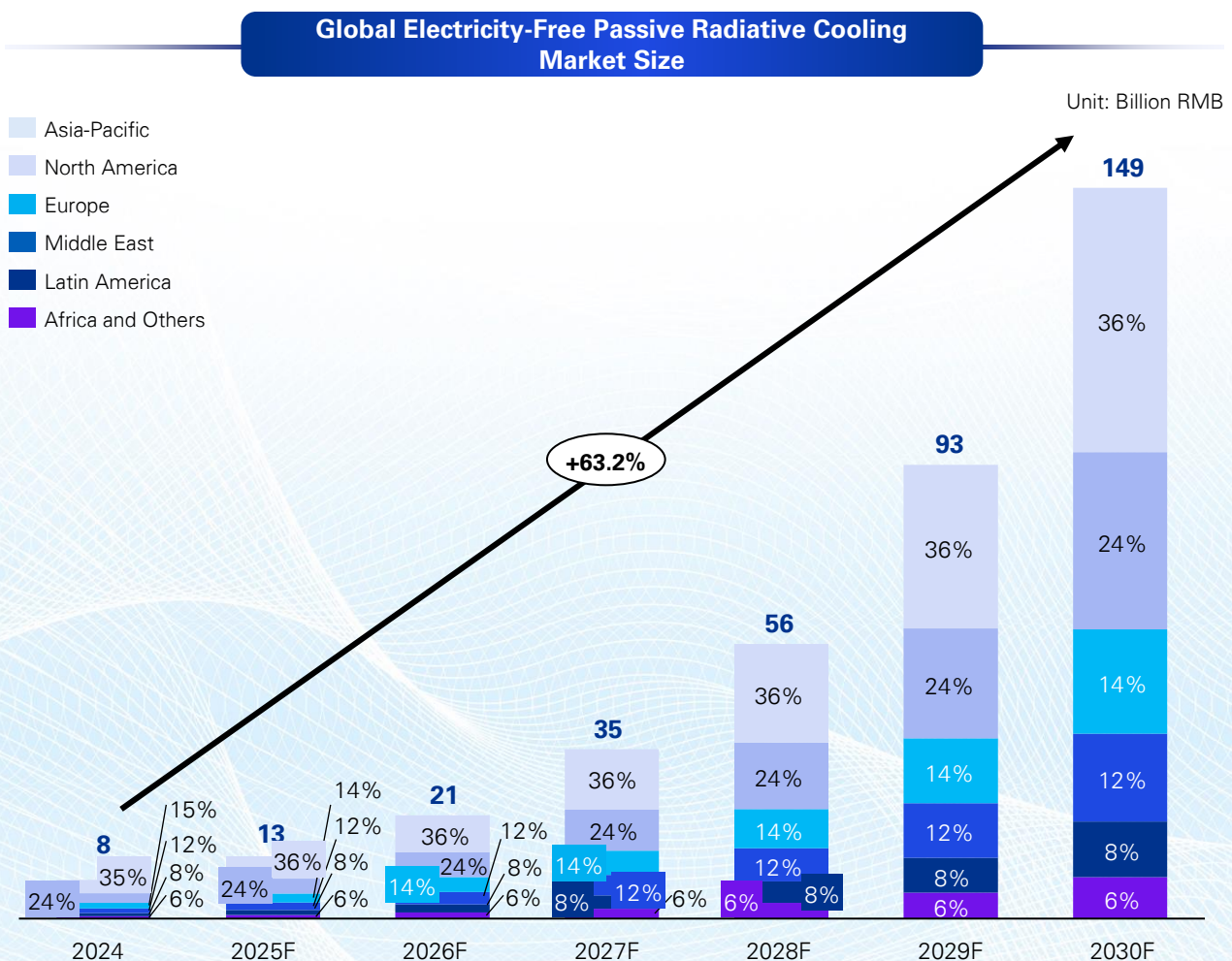
In international markets, developed countries are continuously strengthening policies on green building materials and low-carbon buildings. For example, the energy efficiency incentives under the U.S. 'Green New Deal', the EU's green certification system favouring high-performance envelope materials, and the strong demand in hot-climate regions such as the Middle East and Southeast Asia all present substantial spillover opportunities for this technology. Particularly in rapidly growing cities across the 'Global South', where cooling electricity resources are relatively limited, electricity-free cooling products can serve as important supplementary tools for public facility cooling and basic livelihood support, offering inherent adaptability advantages and deployment cost-effectiveness.

In the long term, with the gradual implementation of carbon pricing mechanisms and the strengthening of ESG mandates, passive cooling products featuring 'zero energy consumption', 'no refrigerants', and 'low lifecycle emissions' are likely to be regarded not only as energy-saving tools, but also as new types of infrastructure for low-carbon asset allocation and green value pricing. In standard systems such as green building evaluations, supply chain decarbonisation, and industrial energy efficiency ratings, this technology is expected to gain greater importance and drive rapid development across the supporting market chain.



As an emerging green cooling pathway, electricity-free passive radiative cooling technology remains in the early stages of development. KPMG has conducted specialised estimation studies across multiple core application industries, establishing a framework of estimation logic and assumptions that covers major scenarios. In the building sector, KPMG selected commercial buildings and other typical high-heat-load building types as representative examples. By integrating regional building area structures and the penetration rate of technical adaptation, the team estimated the potential size of relevant sub-markets. For the chemical industry, the research focused on large-scale chemical parks and the number of representative storage tanks. By assessing the unit protective surface area and the adaptation rate of functional materials, the potential application space was calculated. In the grain storage and logistics segments, the estimation model primarily considered the number of grain depots in high-temperature and high-humidity regions, their individual storage capacities, and the long-term demand for stable temperature control. These factors were combined with the surface area of applicable materials to estimate the potential market capacity. In the field of public infrastructure and transportation systems, the team identified exposed facility scenarios such as bus shelters, transit stations, and outdoor shading structures. Market projections were made based on construction scale and the surface retrofit potential of these structures. In addition, for the functional consumer goods sector, the study also covered quantifiable flexible application scenarios represented by items such as sun umbrellas, clothing, and shading fabrics. The estimation logic was based on annual sales volume, unit usage area, and penetration rate in high-temperature regions. The entire estimation process is supported by a proprietary research model developed by KPMG, referencing cross-sector benchmarking parameters. It aims to provide a systematic and structured market forecast perspective for this report, helping readers of all backgrounds understand the pathways of industry penetration and the growth potential of this technology across different sectors.

### 2.3.1 Global market size



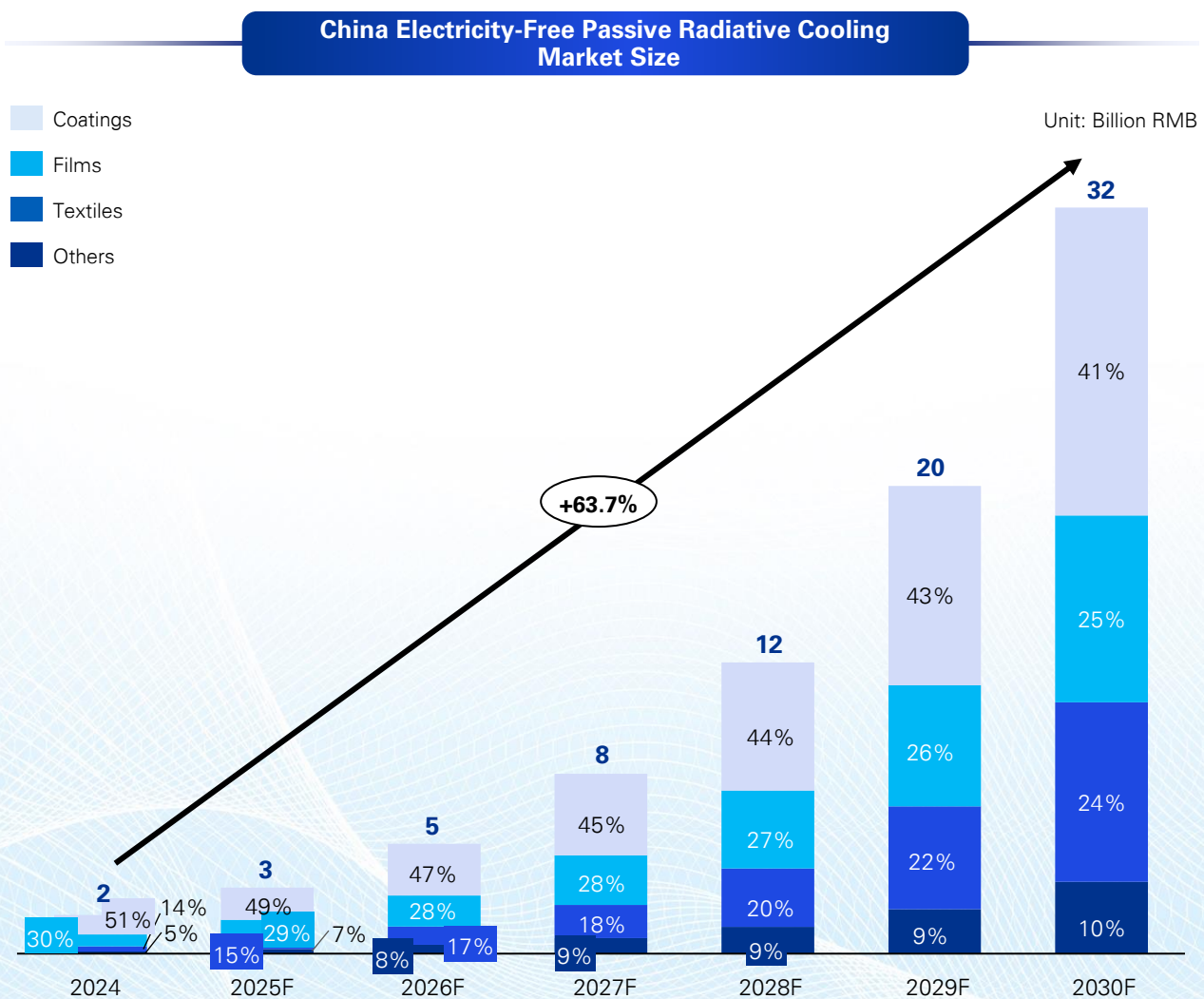
Source: KPMG Analysis

Notes: The above market size data is derived from KPMG's internal research and is provided for analytical display purposes only, for reader reference. All data should not be considered as any form of investment advice or business commitment. KPMG shall not be liable for any decisions, actions, or outcomes based on the use or reference to this data.



Between 2024 and 2030, the global market for electricity-free passive radiative cooling technology is expected to grow rapidly, with broad potential for incremental market expansion. The compound annual growth rate (CAGR) of the global market size is projected to exceed 63% during this period. Notable market growth is anticipated in the Asia-Pacific, North America, and Middle East regions, while penetration rates in industries such as construction, new energy, and automotive are poised for breakthroughs. In addition, the transmission of green premiums and the rising demand for energy-saving cooling solutions have become core driving forces in the market for electricity-free passive radiative cooling technology. The increasing prices of carbon emission allowances and the global rise in electricity prices have created a wide range of compatible application scenarios for radiative cooling materials, including residential buildings, commercial facilities, and industrial plants. The construction, automotive, and property management sectors are actively seeking sustainable and energy-efficient cooling materials to replace conventional cooling systems that heavily depend on electricity and refrigerants.

### 2.3.2 China market size



Source: KPMG Analysis

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China's market for electricity-free passive radiative cooling technology is growing at one of the fastest rates globally, driven by factors such as climate change, energy conservation and emission reduction targets, and technological iteration. Between 2024 and 2030, the market size in China is expected to grow at a high compound annual growth rate of approximately 64%. By 2030, with increasing penetration of application scenarios in the construction and automotive sectors, the coatings and glass film markets will maintain steady development. Meanwhile, emerging applications such as textiles and electricity-free passive radiative cooling tiles will continue expanding, with their market share steadily increasing. Textile-based materials are expected to become a key component of the overall application market.

The growth trajectory of China's electricity-free passive radiative cooling technology market will be driven by a combination of factors, including climate change, energy-saving demands, technological innovation, and policy support:



**Increase in hot and humid weather:** Over the next decade, the number of extreme high-temperature days in China is projected to increase by 7 to 15 days, spurring potential demand for passive cooling materials.

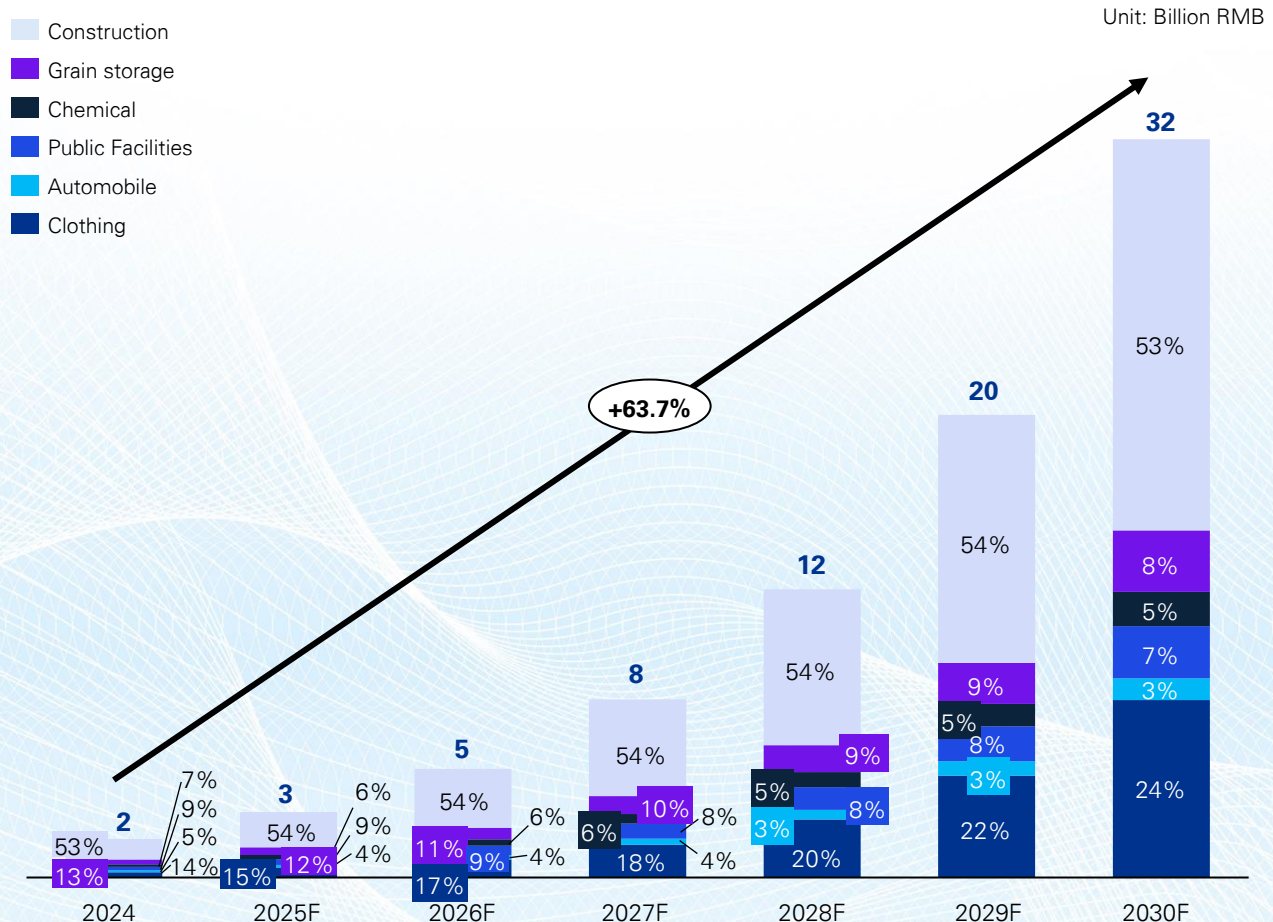


**Energy conservation and emission reduction needs:** In specific climate zones, the use of radiative cooling materials can reduce building operational carbon emissions by 10–16%.



**Technological iteration and evolution:** The development of new nanomaterials, microstructured coatings, and composite films has significantly enhanced the efficiency and durability of passive cooling materials.

### China Electricity-Free Passive Radiative Cooling Market Size (by Industry)



Source: KPMG Analysis

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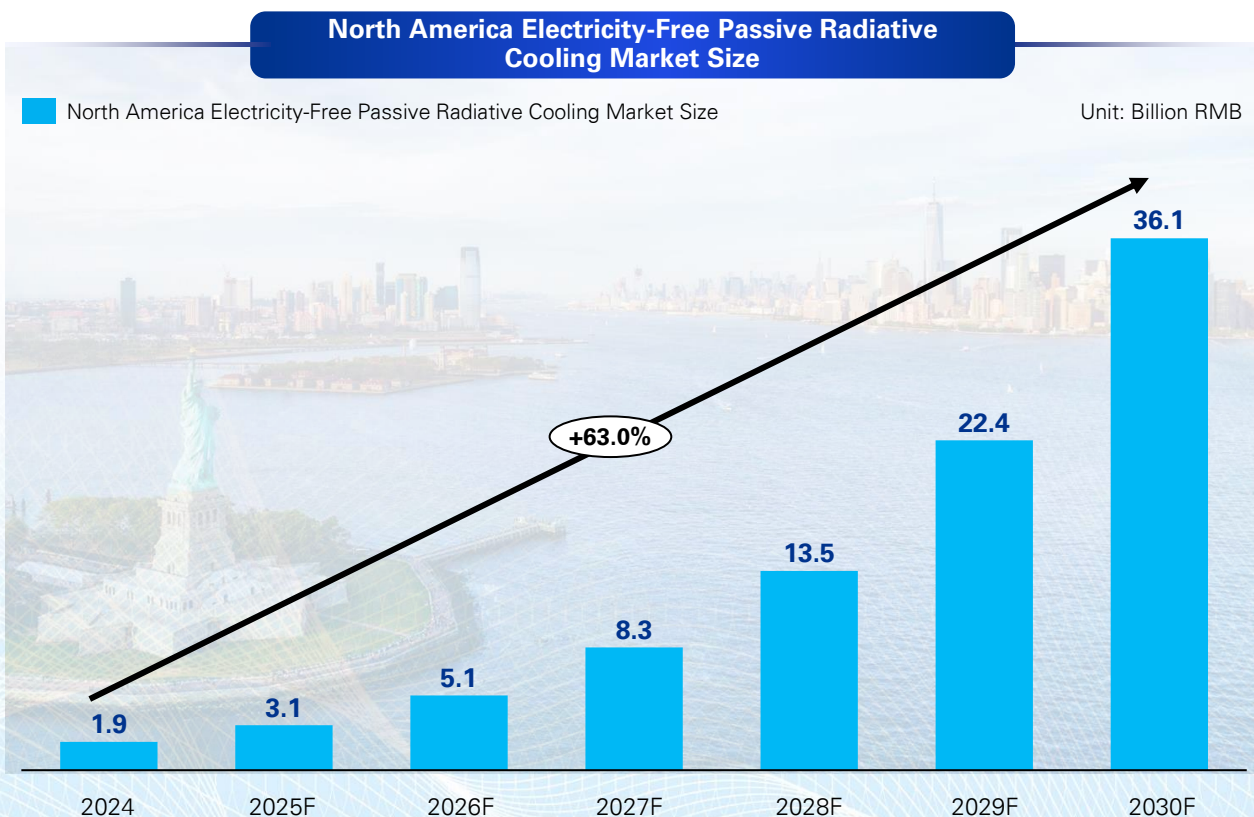


China's electricity-free passive radiative cooling market demonstrates vast application potential across multiple industry scenarios. By 2030, the total market size is expected to reach approximately RMB 3.2 billion, covering key sectors such as construction, grain storage, chemicals, public infrastructure, automotive, and apparel. In terms of structural distribution, the construction sector will be the primary application area, with an estimated market size of RMB 1.693 billion in 2030, accounting for 53% of the total market. This is mainly driven by surface cooling demands for exterior walls, rooftops, and glass curtain walls. As a representative of consumer products, the apparel industry also shows significant potential, with a projected market size of RMB 768 million in 2030, reflecting the rapid penetration of novel functional textile materials in outdoor work, protective wear, and fashion consumption.

Grain storage and public infrastructure also show stable demand, with estimated market sizes of RMB 265 million and RMB 226 million respectively, mainly due to surface temperature regulation needs in granaries, transit stations, and bus shelters exposed to prolonged high-temperature environments. The chemical and automotive sectors have relatively smaller market volumes but serve as typical and demonstrative cases for technological application, with steady growth prospects in equipment protection, tank cooling, and thermal management of new energy vehicle bodies.

Overall, with growing industry awareness and expansion of application scenarios, passive radiative cooling technology is poised to achieve breakthroughs in building energy efficiency, functional consumer goods, and high-temperature operating sectors, fostering a diversified market landscape.

### 2.3.3 Overview of other region markets

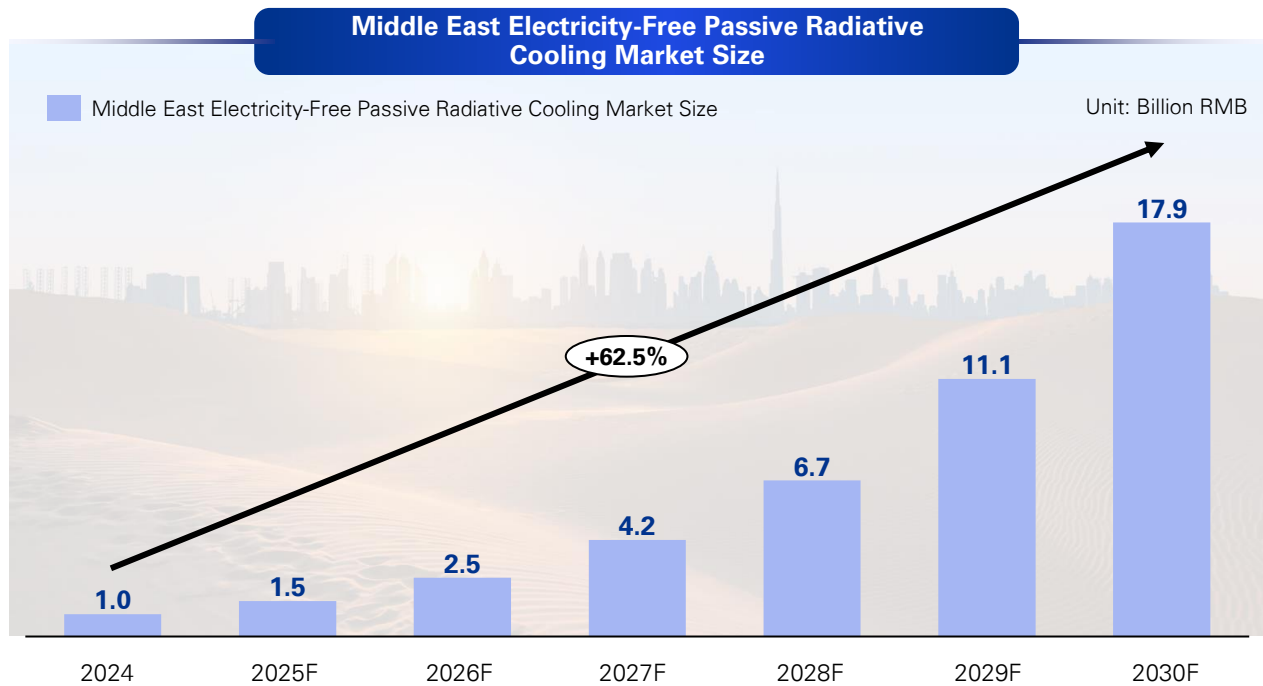


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The North American market features globally leading environmental and energy-efficiency awareness, with relatively mature radiative cooling technologies and higher penetration rates. However, it must simultaneously comply with both federal and state-level regulatory frameworks. Collaborating with local brands to establish industry chain synergies is highly feasible. Between 2024 and 2030, the North American electricity-free passive radiative cooling market is projected to grow from RMB 190 million to approximately RMB 3.61 billion, with a compound annual growth rate of 63%.

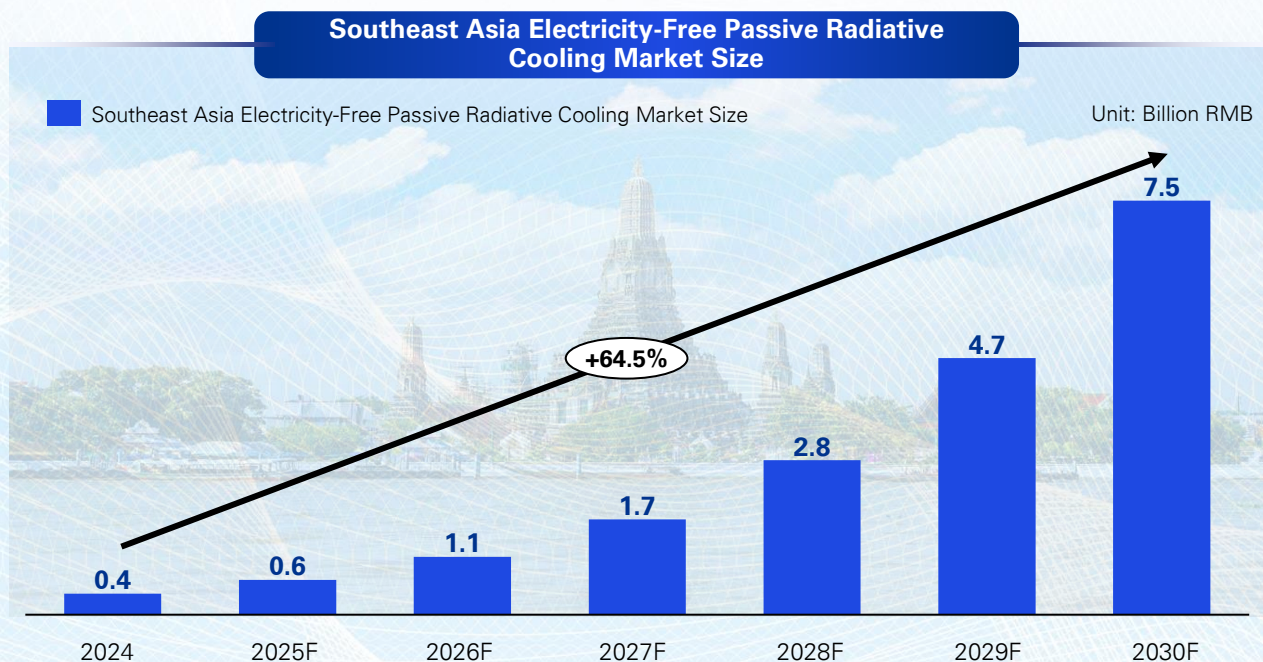




Source: KPMG Analysis

Notes: The above market size data is derived from KPMG's internal research and is provided for analytical display purposes only, for reader reference. All data should not be considered as any form of investment advice or business commitment. KPMG shall not be liable for any decisions, actions, or outcomes based on the use or reference to this data.

The natural environment in the Middle East is highly compatible with electricity-free passive radiative cooling materials. Driven by supportive national policies, emerging application scenarios in the region are experiencing a surge in demand. Collaborating with distributors is expected to become an efficient market entry strategy. Between 2024 and 2030, the Middle Eastern electricity-free passive radiative cooling market is projected to grow from RMB 100 million to approximately RMB 1.8 billion, with a compound annual growth rate of 62.5%.

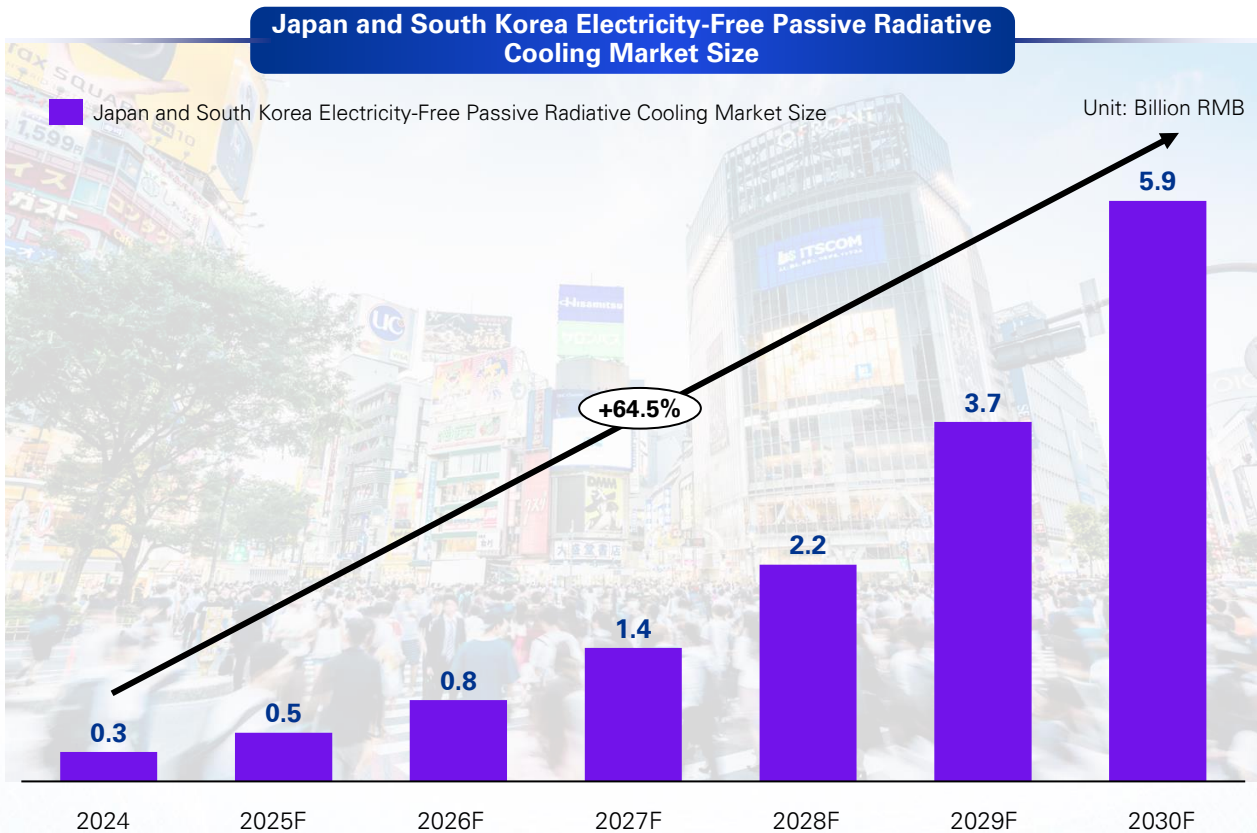


Source: KPMG Analysis

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The Southeast Asian region demonstrates a relatively high level of awareness regarding electricity-free passive radiative cooling technologies. As a result, market regulations and technical certification requirements will become key determinants for market entry, with local partnership network development emerging as a focal point. Between 2024 and 2030, the Southeast Asian electricity-free passive radiative cooling market is projected to grow from RMB 40 million to approximately RMB 750 million, representing a compound annual growth rate of around 65%.



Source: KPMG Analysis

Notes: The above market size data is derived from KPMG's internal research and is provided for analytical display purposes only, for reader reference. All data should not be considered as any form of investment advice or business commitment. KPMG shall not be liable for any decisions, actions, or outcomes based on the use or reference to this data.

The Japanese and South Korean markets exhibit strong potential demand in emerging application areas such as textiles using electricity-free passive radiative cooling materials. However, stringent industry certification standards and significant competitive pressure from local enterprises present challenges. From 2024 to 2030, the electricity-free passive radiative cooling market in Japan and South Korea is expected to expand from RMB 30 million to approximately RMB 590 million, with a compound annual growth rate exceeding 64%.

### 2.3.4 Key market participants

As electricity-free passive radiative cooling technology moves towards commercial deployment, several companies with strong R&D capabilities and application deployment experience have begun to explore the international market. Representative players include SkyCool Systems, SPACECOOL Inc., and i2Cool.

According to information on the official website of SkyCool Systems, the company was founded in 2016 and is headquartered in California, USA. It specialises in the R&D and integrated application of radiative cooling films and rooftop panels. Its products can operate independently or in conjunction with air conditioning systems to improve cooling efficiency and reduce energy consumption. In several projects, these panels have been applied to commercial building rooftops and cold chain systems for thermal management, achieving sustained daytime cooling under ambient temperature conditions.



According to information on the official website of SPACECOOL Inc., the company was founded in 2021 as a passive cooling materials venture jointly established by Japanese and American technical teams. Its core products feature multi-layer spectrally selective films with flexibility-compatible substrates and come in various forms including shading films, waterproof fabrics, and equipment coatings, suitable for surface temperature regulation in transportation, industrial, and building infrastructure applications. In terms of material standardisation, SPACECOOL has participated in joint projects in Europe for testing, evaluation, and lifetime validation of passive radiative cooling materials.

According to information on the official website of i2Cool, the company originated from a research team at City University of Hong Kong and was founded in 2022. It primarily develops cooling materials based on nanoparticle composite structures with high solar reflectance and mid-infrared emissivity. Product forms include coatings, films, ceramic modules, and textiles, suitable for applications such as building rooftops, industrial equipment, and photovoltaic modules. Its products have already been deployed in demonstration projects across multiple regions, covering applications in building energy efficiency, urban infrastructure, and energy equipment.

These companies exhibit distinct characteristics in terms of material mechanisms, product formats, and application pathways, reflecting a trend in the passive radiative cooling industry towards diversified exploration, transitioning from scientific validation to integrated engineering deployment.

## 2.4 Energy Conservation and Emission Reduction Policies Driving Industry Growth

Under the guidance of the ‘dual carbon’ strategy and the acceleration of global climate commitments, the policy status of energy-saving and cooling solutions is steadily rising. Conventional active cooling methods that rely heavily on electricity and high-GWP refrigerants face multiple challenges related to carbon reduction, pollution control, and system resilience, prompting countries worldwide to seek breakthroughs at the technological source. Among them, nature-synergistic technologies represented by electricity-free passive radiative cooling are gradually gaining the attention of policymakers and have been explicitly positioned in a series of strategies, standards, and incentive mechanisms.

At the international level, the United Nations Environment Programme (UNEP) has designated ‘sustainable cooling’ as a core task for implementing the Kigali Amendment, explicitly calling for support to promote passive and natural cooling technologies in building, transportation, and industrial systems. In 2022, the World Bank released its ‘Cooling Action Plan’, emphasising that developing countries should prioritise the deployment of affordable, structurally simple, and environmentally friendly cooling technologies—such as radiative cooling and night cooling—to mitigate peak electricity load and extreme climate risks in both urban and rural areas.

China’s policy framework is also actively encouraging the diversified development of green cooling pathways. The ‘14th Five-Year Plan for Comprehensive Work on Energy Conservation and Emission Reduction’ released in 2021 explicitly calls for upgrading energy-saving technologies in buildings and promoting the use of natural cooling sources, passive energy-saving structures, and high-performance materials. The ‘General Code for Building Energy Efficiency and Renewable Energy Utilisation’ issued by the Ministry of Housing and Urban-Rural Development (MOHURD) also, for the first time, lists passive cooling as a recommended option and allocates credit weight to it in green building evaluation standards, encouraging its integration into rooftops, exterior walls, and building envelopes.





## Industry Overview: Policies and Regulations

Relevant policies and standards are being gradually introduced globally to support the promotion and development of electricity-free passive radiative cooling technology

### Chinese Mainland Relevant Policies

#### National Development and Reform Commission – Action Plan for Green and Efficient Cooling

- **Promoting green and efficient cooling consumption:** Improve the government procurement system for energy-saving and environmentally friendly products, expand the scope of green government procurement, and increase support for the procurement of innovative green and efficient cooling products
- **Improving policy measures:** Encourage local governments to further innovate support mechanisms for green and efficient cooling products and to broaden the range of support channels

#### Ministry of Housing and Urban-Rural Development – Energy Efficiency Design Standard for Public Buildings

- **Promoting the use of energy-saving materials in new and renovated buildings:** Recommend the use of materials with high reflectivity and low heat absorption to reduce cooling loads in buildings
- **Formulating design standards:** Set detailed requirements for the use of energy-saving materials in newly constructed and renovated buildings

#### Ministry of Housing and Urban-Rural Development – 14th Five-Year Plan for Building Energy Efficiency and Green Building Development

- **Enhancing energy-efficient and green building retrofits:** Promote ultra-low energy consumption building projects, carry out energy-saving renovations of existing residential buildings, and advance the development of key cities for public building energy efficiency improvement
- **Supporting the use of green building materials:** Increase investment in the R&D of green building materials and core technologies, and encourage the development of high-performance prefabricated components

#### China Association for Engineering Construction Standardisation – Radiative Cooling Coatings for Buildings

- **Improving definitions and standards to promote industry standardisation:** Define terminology, requirements, testing methods, inspection rules, and test reporting for radiative cooling coatings used in buildings, providing general industry standards for building roofs and exterior walls to support regulatory standardisation

### Hong Kong SAR Relevant Policies

#### HKSAR Government – Hong Kong's Climate Action Plan 2050

- **Enhancing the application of innovative cooling materials:** Recognise passive cooling materials as an effective means of improving building energy efficiency and support their use in buildings and public infrastructure in the context of achieving carbon neutrality by 2050
- **Improving energy efficiency of buildings:** Enhance energy-saving and emission reduction performance in buildings, reduce overall electricity consumption, and strengthen the implementation of low-carbon lifestyles

### Key International Policy References

#### International Energy Agency – The Future of Cooling

- **Reducing electricity demand through passive cooling materials:** Reduce power loads and emissions by improving the energy efficiency of cooling equipment and using passive cooling materials
- **Encouraging passive cooling solutions:** Mitigate the need for new power plants and promote the use of passive cooling solutions in building design to address future increases in 'cooling load'

#### European Commission – Energy Performance of Buildings Directive (EPBD)

- **Encouraging the use of innovative cooling materials to reduce urban heat island effects:** Promote the application of passive cooling materials at both building and urban levels to mitigate the urban heat island effect
- **Promoting renovation of existing buildings:** Define national strategies and practical solutions for achieving zero-carbon building stock, and guide the construction sector in phased retrofitting with innovative cooling materials to meet zero-emission targets

In terms of green finance and fiscal incentives, many regions have included cooling materials and systems with passive energy-saving effects in the recommended catalogues for green building products and the scope of fiscal subsidies. For example, Shenzhen has listed 'new roofing materials with reflective and radiative cooling properties' as part of the support scope for near-zero energy buildings, offering financial subsidies of more than RMB 50 per square metre. Jiangsu and Zhejiang have also prioritised the use of demonstrative passive cooling technologies in pilot projects such as smart parks and green construction sites, creating a positive interaction between policy and application. Notably, policy focus is gradually shifting from supporting single technologies to endorsing 'system-level solutions'. This sets a higher bar for enterprises, requiring not only material R&D capabilities but also the ability to achieve system adaptation and functional integration in complex scenarios. Against this backdrop, some Chinese companies have successfully transformed from material suppliers into system solution providers, participating in multiple demonstration projects and policy pilot evaluations, showcasing a keen responsiveness to policy direction and engineering implementation capacity.

As national support intensifies for energy-saving building materials, green processes, and low-carbon system integration, enterprises with original material systems, mass production capabilities, and multi-scenario integration experience are expected to stand out in future competition. It is foreseeable that policy mechanisms will play a key role in the standardisation, scaling, and commercialisation of electricity-free passive cooling technologies, promoting their transformation from 'cutting-edge materials' to 'infrastructure components'.

## 2.5 Market Trends and Sustainable Investment Accelerating Industry Deployment

While the policy framework continues to improve, market-driven demand for green and low-carbon cooling technologies is also growing rapidly, becoming another core force accelerating the deployment of electricity-free passive radiative cooling materials. In multiple high-temperature and heat-load industries—such as construction, manufacturing, transportation, and energy—traditional cooling methods face increasingly prominent challenges such as high energy consumption, large maintenance costs, and poor environmental adaptability. These challenges are pushing end users to proactively seek new cooling solutions that are cost-effective, stable in operation, and environmentally friendly. Passive radiative cooling materials, with their advantages of not relying on energy input, flexible structural integration, and low maintenance burden, are attracting growing market attention. The number of demonstration projects is steadily increasing, and the scope of application continues to expand.

At the same time, the accelerated development of ESG investment and green finance systems is providing stronger capital support for the industry. In 2023, global investment in green buildings and climate-resilient materials increased significantly, with most funding directed towards basic building materials and system integration companies directly linked to energy conservation and emissions reduction. An increasing number of industrial capital providers, infrastructure funds, and real estate operators are treating 'green cooling capability' as an important reference criterion in project evaluation and procurement, driving passive cooling technologies from proof-of-concept to commercial deployment. Meanwhile, corporate ESG management requirements are also speeding up the pace of green transformation. Especially for asset operators with high heat loads—such as data centres, logistics warehouses, and manufacturing bases—there is growing momentum to deploy energy-free new cooling materials to meet carbon neutrality and disclosure compliance requirements.

Overall, electricity-free passive radiative cooling materials are entering a growth window driven by both 'policy pull' and 'market push'. On one hand, they are continuously supported by energy-saving and emissions-reduction policies, green building codes, and fiscal mechanisms. On the other hand, their practical value and investment appeal across multiple industries are rapidly increasing. Looking ahead, as the acceptance of the 'zero-energy cooling' concept improves among developers, industries, and end users, such technologies are likely to shift from being 'bonus features for energy savings' to becoming 'standard configuration options', paving the way for a stable market-driven development trajectory.



# 03

## Product Innovation Highlights and Application Advantages

As electricity-free passive radiative cooling technology continues to evolve from fundamental material research towards real-world application, industry competition is increasingly shifting towards product integration capabilities, system adaptation efficiency, and depth of scenario-based deployment. Leading enterprises are pursuing differentiated innovation across key dimensions such as spectral response performance, structural stability, and environmental adaptability. Through modular and standardised product designs, they are facilitating the transition of cooling materials from 'research-oriented materials' to 'engineering-ready solutions'. Currently, the market features a variety of well-defined product forms with diverse structures, including highly reflective and emissive composite films for building rooftops, cooling coating modules for logistics and industrial storage, and lightweight passive cooling textiles for personal protection and consumer scenarios. These products are undergoing continuous iteration in terms of performance parameters, durability, safety, and manufacturing compatibility, and they now demonstrate broad engineering adaptability, enabling integration with a wide range of terminal interfaces such as building structures, equipment enclosures, and transportation platforms.

Some technology-leading enterprises are leveraging proprietary material systems and process platforms to build a product ecosystem that spans 'functional films – intermediate modules – end-use solutions'. Through engineering-level integration and large-scale delivery, they are achieving effective deployment across various application scenarios. Teams with strong contextual understanding and interdisciplinary integration capabilities are often able to transition more quickly from proof-of-concept to commercial feasibility, gaining a clear first-mover advantage in pilot projects and policy demonstration programmes.

Against the backdrop of growing green building initiatives, urban renewal programmes, and enhanced mechanisms for coping with extreme heat conditions, electricity-free passive radiative cooling products are gradually becoming a key component of the next generation of cooling materials. Promoting their deep integration into critical industries and priority use cases will generate tangible cooling and carbon-reduction benefits for low-carbon buildings, green transportation, and smart logistics, while opening up significant development opportunities for companies with product innovation capabilities.

## 3.1 Introduction and Advantage Analysis of Mainstream Products

The global electricity-free passive radiative cooling market has already begun to take shape as an emerging industrial ecosystem. Representative players include SkyCool, SpaceCool, and i2Cool, with product offerings covering coating materials, film-based materials, and composite structural materials. These solutions are widely applied in building energy efficiency, photovoltaic systems or solar power generation, cold chain logistics, and outdoor equipment. Compared with traditional cooling methods, electricity-free passive radiative cooling technologies can achieve continuous cooling without external energy consumption, offering advantages such as zero energy use, low carbon emissions, and broad applicability. These characteristics are attracting growing global attention amid rising energy efficiency and emission reduction targets.

In contrast, the domestic market remains in a technology-driven early stage. Many of the relevant Chinese companies have been incubated by universities or research institutions, possessing strong material R&D capabilities, but still in the exploratory phase regarding industrialisation pathways, scaled deployment, and commercialisation mechanisms. At present, domestic players are actively expanding demonstration projects in key sectors such as buildings, storage and transport, and energy, steadily transforming technical achievements into practical market applications.

Currently, electricity-free passive radiative cooling technology is entering a phase of rapid productisation and expansion. Product forms have progressed from early experimental materials to an engineering-grade product system characterised by structural diversity, functional stability, and multi-scenario adaptability. A mature product spectrum is gradually emerging in the market, with major categories including 'functional coatings – composite films – structural ceramics – optical automotive paints – functional fabrics'. These are now being widely applied in surface layers of buildings, equipment shells, road infrastructure, cold chain warehouses, photovoltaic systems, and individual thermal protection use cases.



In terms of material performance, electricity-free passive radiative cooling materials typically exhibit spectrally selective characteristics with high reflectivity and high emissivity. Their solar reflectance and mid-infrared emissivity can both exceed 95%, enabling surface temperature reductions of 10 to 40°C under typical climate conditions, with some scenarios achieving measured cooling effects exceeding 42°C. These materials come in various forms, such as coatings and films, and demonstrate strong adaptability and flexibility across use cases. Among them, coating-type materials are widely applied to building rooftops, exterior walls, storage facilities, and outdoor equipment surfaces. They offer the advantages of easy application, large coverage areas, and compatibility with diverse substrate materials, making them one of the most mature product types in current applications. Film-based materials, on the other hand, feature excellent light transmittance and colour uniformity, making them well-suited for diversified applications with high visual and optical requirements, such as glass facades, vehicle structures, and urban curtain wall systems. These materials effectively balance thermal management with visual comfort. Each product category offers unique advantages:



Functional coatings are characterised by simple structure and strong adaptability, covering multiple major product forms, including liquid coatings (i.e., paints) that can be directly sprayed onto walls, rooftops, and equipment surfaces; roll materials made by coating substrates and compounding them with functional adhesives; and emerging electricity-free cooling powder coatings. Among these, roll-type products offer strong waterproof performance and are suitable for outer building layers and protective surfaces. Powder coatings show significant potential in enhancing application efficiency and material stability. Overall, functional coatings provide excellent cooling, weather resistance, corrosion protection, and anti-fouling properties, making them suitable for high-temperature, sun-exposed regions and complex infrastructure environments, and offering highly adaptable thermal management solutions across diverse use cases.



High-performance films are lightweight, flexible, and offer high spectral control precision. They can effectively block ultraviolet and infrared radiation while maintaining high visible light transmittance. These films are widely used in energy-efficient glass, door and window systems, and vehicle interior components, effectively reducing air-conditioning loads and improving indoor thermal comfort.



Structural ceramics and engineered bricks are developed based on inorganic porous systems, offering outstanding thermal radiation performance, mechanical strength, and fire resistance. They are applicable for paving surfaces, external walls, and roofing in high-temperature areas, delivering combined functions of cooling, slip resistance, pollution resistance, and mitigation of urban heat island effects. These materials are ideal for green campus developments and smart city renovation projects.



Automotive coating materials leverage ultra-fine particles and resin systems to achieve stable adhesion and thermal regulation over complex curved surfaces. They are suitable for use on car rooftops and external shells, delivering effective temperature control in outdoor scenarios.



Thermoregulating textiles combine high-emissivity fibres with nano-reflective coating techniques and are applied in uniforms, functional outdoor clothing, and building shading systems. These fabrics help reduce skin surface temperature and improve user thermal comfort, making them suitable for high-temperature urban workplaces and outdoor exposure environments.

From a process capability perspective, mature enterprises have achieved large-format continuous production, modular cutting, and batch delivery capabilities. Some products now support standardised application techniques such as roll-to-roll coating, automated film application, and rapid spraying, resulting in high engineering delivery efficiency and convenient system integration. Enhanced with additional features such as fire resistance, corrosion resistance, and anti-ageing performance, these products can meet long-term usage requirements across different regions and climatic conditions. Moreover, they have passed multiple regional and industry-specific green building certification systems, including environmental standards for building materials, energy-saving and emission-reduction performance tests, and green building design catalogues. Some products have been successfully deployed in nearly zero-energy building demonstration projects, urban renewal initiatives, and green industrial parks, with their energy-saving effects, cooling load reduction, and life-cycle cost-effectiveness widely recognised.

Enterprises with full-chain development capabilities are accelerating the large-scale adoption of electricity-free passive radiative cooling products through a model combining 'proprietary material systems + application product matrices + multi-scenario adaptability'. The success of these products stems not only from technological breakthroughs in materials but also from a precise understanding of real-world application demands and continuous refinement of engineering pathways. These solutions are becoming essential components in the construction of low-carbon cooling systems.



## 3.2 Panorama Demonstration of Application Scenarios

As urban heat island effects intensify and energy costs continue to rise, various energy consumption scenarios are placing increasingly high demands on the performance, form, and deployment flexibility of cooling materials. Electricity-free passive radiative cooling products, characterised by their 'zero energy consumption', 'flexible structural integration', and 'multi-material system compatibility', have already been deployed and validated in several key scenarios, demonstrating systemic advantages over conventional thermal insulation materials.

### Multi-Scenario Applications

#### Construction



##### Library, Guangzhou

Measurement time: Jun - 2023

Max surface cooling ↓ **42.9°C**  
Energy-saving rate of application floor ↑ **39.5%**

#### Logistics



##### Container, UAE

Measurement time: July - 2023

Max surface cooling ↓ **29.9°C**  
Max internal cooling ↓ **6.8°C**

#### Power Communication



##### Ring Main Unit, Fujian

Measurement time: Sep - 2023

Max surface cooling ↓ **38°C**  
Max equipment internal cooling ↓ **14.9°C**

#### Grain Storage



##### Granary, Hainan

Measurement time: Feb - 2024

Max Granary surface cooling ↓ **30.9°C**  
Save costs ↓ **25%**

#### Chemical Industry



##### Gas storage tank, HK China

Measurement time: July - 2023

Liquid inside the tank cooling ↓ **9°C**  
Save cooling costs % ↓ **60%**

#### Photovoltaics



##### Photovoltaic panels, HK China

Measurement time: June - 2023

Max surface cooling ↓ **25.7°C**  
Improve power generation efficiency % ↑ **8%**

#### NRSE



##### Energy storage cabinet, Guangdong

Measurement time: Nov - 2023

Max surface cooling ↓ **34.8°C**  
Internal cooling up to ↓ **8°C**

#### Automotives



##### Buses, HK China

Measurement time: Oct - 2023

Average cooling inside the car ↓ **4.6°C**  
Energy savings can reach ↓ **26%**

### 1). Green Buildings and Urban Renewal Projects

In high-density urban areas such as office buildings, residential complexes, and public facilities, external walls, rooftops, and glass curtain walls are the main channels of thermal gain. Electricity-free passive radiative cooling materials can be widely applied to rooftops, exterior walls, and glass façades through coating spray, glass film application, or ceramic panel installation. Under typical summer climate conditions, these materials can reduce surface temperatures by 10–40°C and decrease cooling system loads by approximately 30–40%, effectively improving indoor thermal conditions, extending the service life of air-conditioning equipment, and reducing peak electricity demand.



According to some practical industry case studies, when the unit-area cooling load of a building is reduced by 30%, the corresponding electricity consumption can be lowered by 25–35 kWh/m<sup>2</sup>·year. Based on the carbon emission factor of approximately 0.7–0.9 kg CO<sub>2</sub>/kWh in southern China, the annual carbon emission reduction from retrofitting 100 square metres of building façade is estimated at 2.0–3.0 tonnes. Although the carbon reduction potential varies by building type, climate, and usage patterns, it offers significant cumulative carbon savings at the building cluster scale, providing a realistic pathway for ‘source-level carbon reduction’ in the building sector.

In urban renewal and near-zero-energy building pilot projects, these materials are increasingly incorporated into green building systems as key components that meet new envelope thermal performance standards. They are used in schools, hospitals, urban complexes, and public transportation hubs undergoing energy-efficiency upgrades, offering advantages such as easy construction, low operational burden, and strong life-cycle cost efficiency. As carbon performance requirements for green buildings continue to increase, passive radiative cooling is expected to play an increasingly important role in carbon evaluation, carbon asset quantification, and green finance alignment.

## 2). Industrial Warehousing and Cold Chain Logistics Systems

In applications such as logistics parks, cold chain containers, warehouse rooftops, and chemical storage tanks, extreme temperature differences, high cooling loads, and enclosed environments demand materials with high durability and strong cooling performance. Electricity-free passive radiative cooling coatings and ceramic products can be directly applied or embedded onto the surfaces of metal tanks, shipping containers, and modular roof structures. Measured surface temperature reductions are generally in the range of 30–40°C, with interior cold-chain vehicle temperatures decreasing by approximately 4–6°C and refrigeration equipment energy consumption reduced by 20–30%. This not only improves the quality of storage and transportation but also significantly lowers cold chain operational costs and extends cooling system lifespans. Some ceramic products also offer fire resistance, corrosion protection, and UV durability, making them suitable for coastal regions with high humidity, salinity, and solar radiation, thereby improving the thermal resilience of warehousing and supply chain infrastructure.

## 3). Energy and Equipment Thermal Management Systems

In sectors such as power, telecommunications, new energy, and petrochemicals, numerous outdoor control cabinets, energy storage units, transformers, base stations, and equipment housings are continuously exposed to high-temperature environments, making thermal management a critical aspect of operations and maintenance. In typical cases, electricity-free passive radiative cooling products are applied to cabinet tops, façades, and internal reflective surfaces, reducing external shell temperatures by over 30°C and internal temperatures by 10–15°C. This extends the lifespan of core components by approximately 20–30%, lowers accident risks, and enhances overall system stability.

In photovoltaic scenarios, these products can be used on frames, backplates, or support structures for thermal reflection and dissipation, helping to reduce thermal losses and improve panel efficiency by about 6–8%. These deployment methods are low-cost, easy to maintain, and do not affect the structure of power-generating components, making them a feasible option for ‘zero-energy cooling’ in solar energy systems.

## 4). Urban Transportation and Automotive Systems

Urban roads, high-temperature parking areas, and public transit systems are typical ‘localised heat island’ environments. Lightweight and highly adhesive radiative cooling coatings for vehicles can be sprayed onto car exteriors, rooftops, and engine hoods. Measured reductions in cabin temperature reach 3–5°C, with interior surface temperatures decreasing by 20–30°C, thereby enhancing passenger comfort and reducing in-vehicle air conditioning energy use without electricity consumption. These products are compatible with various vehicle types and aesthetic requirements of urban infrastructure due to their flexible colouring and application methods. They are already being adopted in city buses, logistics vehicles, and private cars.

## 5). Personal Thermal Comfort and Lightweight Applications

In lightweight applications such as high-temperature work environments, outdoor sports, and portable settings, textiles with radiative cooling functions are emerging as new solutions for enhancing individual thermal comfort. These materials combine fabric structural regulation with infrared radiation coating treatments to enhance heat dissipation, partially reflect solar heat, and optimise thermal conduction pathways. Without relying on external energy, they help reduce perceived body temperature and alleviate heat stress discomfort. Related products have already seen widespread adoption in sanitation, construction, transportation, and public safety sectors with prolonged heat exposure, and are gradually expanding into consumer applications such as functional clothing, sun umbrellas, and lightweight shading fabrics.



## 3.3 Industry Case Studies

### 3.3.1 Background of Technology Incubation

i2Cool was established in 2022 and is one of the earliest innovative companies in Asia focusing on the application of electricity-free passive radiative cooling technology. Leveraging the transformation of university research achievements, the company quickly realised the engineering implementation of its technology. Its business has expanded into multiple sectors, including construction, energy, and transportation, with project deployments established in various countries and regions around the world. As a representative market practice case in this field, its development path reflects a typical model of how emerging green and low-carbon technologies transition from laboratory research to large-scale industrial application.

Through continued application in diversified scenarios, the company has generated a notable demonstration effect in promoting the adoption of new cooling materials, enriching the technological pathways of green buildings, and enhancing thermal management capabilities in high-temperature industries, further driving the awareness and adoption rate of electricity-free passive radiative cooling technology across the industry.

### 3.3.2 Product System Development and Technical Features

To meet cooling demands in different scenarios, electricity-free passive radiative cooling technology has developed a multi-type material system, covering various forms such as rigid, flexible, and transparent applications, offering high adaptability and integrability. The following are the brief technical characteristics and main application directions of typical products:

|  |   |  |
|--|---|--|
| <b>Electricity-Free<br/>Passive<br/>Radiative<br/>Cooling Coatings</b>           |  | <p>Electricity-free passive radiative cooling coatings reduce thermal load on buildings and equipment surfaces by employing surface structures with high solar reflectance and high mid-infrared emissivity, effectively lowering surface heat gain and relieving energy consumption pressure caused by environmental temperature rise. These materials are suitable for a variety of interfaces exposed to prolonged sunlight, including rooftops, exterior walls, industrial equipment housings, and exterior infrastructure structures. They are widely used in scenarios such as building energy-saving retrofits, cooling of power equipment, temperature control in chemical and storage facilities, grain storage, and thermal management of new energy enclosures, playing a positive role in improving system operational stability and extending equipment lifespan.</p> |
| <b>Electricity-Free<br/>Passive<br/>Radiative<br/>Cooling Films</b>              |  | <p>These films achieve a balance between light transmittance and thermal insulation through multilayer optical interference structures, making them suitable for glass curtain walls, windows, automotive windows, and transparent photovoltaic module surfaces, and are widely applied in office buildings, vehicles, and agricultural greenhouses where both daylighting and thermal control are required.</p>   |
| <b>Electricity-Free<br/>Passive<br/>Radiative<br/>Cooling<br/>Membrane Rolls</b> |  | <p>These materials combine excellent waterproof performance with construction convenience, making them suitable for various roof coverings, integrated waterproof and thermal insulation projects, and outer structures of industrial facilities with high durability requirements. They are currently widely used in scenarios such as factory rooftops, transportation infrastructure, logistics warehouse roofs, new energy stations, and exterior systems of temporary buildings, demonstrating good results in improving overall thermal management of buildings and facilities, slowing material ageing, and reducing cooling loads.</p>   |



|   |   |  |
|---|---|--|
| <b>Electricity-Free Passive Radiative Cooling Textile Materials</b>   |  | Through the synergistic application of thermosensitive fibre design and radiative cooling structures, electricity-free passive radiative cooling textile materials are gradually being extended to various lightweight scenarios. Firstly, cooling fabrics are primarily used for wearable applications in direct contact with the human body, improving the wearing experience in high-temperature environments and suitable for high-heat labour scenarios such as outdoor operations and protective clothing. Secondly, reflective fabrics create large-scale shading structures through high-reflectivity textile surfaces, effectively blocking solar radiation. These are commonly used in umbrellas, canopies, sunshades, and tent tops, providing thermal protection support for outdoor activities. |
| <b>Electricity-Free Passive Radiative Cooling Ceramic Tiles</b>       |  | These are functional ground paving materials with the capability to reflect thermal radiation, mainly used in outdoor public spaces such as urban plazas and park walkways. They help alleviate local heat island effects and improve surface temperature environments.  |
| <b>Electricity-Free Passive Radiative Cooling Automotive Coatings</b> |  | These functional coatings are used for temperature control on the surfaces of transportation vehicles, reducing heat absorption and internal temperature rise. They have been piloted in cold chain logistics, electric vehicles, and high-temperature operational vehicles, demonstrating practical benefits in load reduction and extending service life.  |

Data source: i2COOL

### 3.3.3 Multi-Industry Application Practices

With growing attention to energy conservation, emission reduction, and thermal environment improvement, electricity-free passive radiative cooling technology has seen initial adoption in multiple industries. It demonstrates strong cross-scenario adaptability and offers a complementary thermal control path beyond traditional energy systems.

#### 1). Buildings and Urban Infrastructure

In the building sector, this type of technology is primarily applied to external envelope structures such as rooftops, exterior walls, and glass curtain walls to reduce overall thermal load and ease the pressure on cooling systems. Compared with traditional energy-saving materials, radiative cooling materials offer more significant temperature control effects and operational stability, and have already been incorporated into energy-saving systems in some green building demonstration projects. At the urban infrastructure level, these materials are also used for surface temperature control in public spaces such as plazas, bus shelters, and pedestrian systems, contributing to the mitigation of urban heat island effects and improving thermal environments, thereby enhancing thermal comfort for residents during summer travel and outdoor activities. Representative application cases include:

- Case 1 – Energy Efficiency Retrofit Project of Mong Kok Complex, Hong Kong: After applying electricity-free radiative cooling coatings to the exterior walls of a large shopping mall and office complex in Mong Kok, the surface temperature of the wall dropped by up to 30.3°C, and the indoor temperature decreased by 10°C, with the floor's energy savings rate reaching 42%, significantly improving the building's overall energy efficiency.
- Case 2 – Thermal Environment Optimisation Project of Kowloon Sports Centre, Hong Kong: After the application of radiative cooling materials to the building's exterior structure, the surface temperature decreased by up to 13.1°C, and annual electricity savings exceeded 300,000 kWh, meeting the comfort requirements of large-scale public spaces while effectively reducing operating costs.



## 2). New Energy and Power Equipment

In the fields of photovoltaic power plants, energy storage systems, and power transmission and distribution equipment, electricity-free passive radiative cooling materials are widely used for surface heat dissipation and enclosure temperature control. They effectively address the heat buildup caused by prolonged sunlight exposure and reduce the risks of decreased photoelectric conversion efficiency, accelerated thermal ageing, and operational instability due to high temperatures. Compared with active cooling solutions, these materials offer advantages such as independence from electricity, easy installation, and cost control, making them particularly suitable for maintenance needs in remote, hot, or unattended areas. They have become an ideal thermal control solution for improving the overall energy efficiency and reliability of new energy systems. Representative application cases include:

- Case 1 – Photovoltaic System Temperature Control Optimisation Project in a Chinese Factory: In a corporate office building, radiative cooling coatings were applied to approximately 1,200 square metres of rooftop solar panel bases, resulting in a surface temperature drop of up to 25.7°C and an average photovoltaic power generation efficiency increase of about 8%, significantly mitigating performance degradation caused by overheating.
- Case 2 – Enterprise Energy Storage Equipment Cooling Upgrade Project: A Chinese energy enterprise applied radiative cooling materials to 300 square metres of energy storage cabinet surfaces, achieving a surface temperature reduction of up to 34.8°C and an internal temperature drop of up to 8°C. This effectively enhanced thermal stability and operational safety without altering the original structure and electrical systems.

## 3). Transportation and Logistics Systems

Electricity-free passive radiative cooling materials have gradually been adopted in transportation equipment such as cold chain logistics, city buses, and electric delivery vehicles, applied to vehicle shells, roof structures, and container surfaces for thermal management retrofits. With notable surface cooling effects, they effectively reduce internal temperatures and air conditioning loads, extending equipment service life while indirectly enhancing vehicle energy efficiency and range performance. In high-energy-consumption scenarios such as cold chain and fresh product transportation, these materials provide tangible benefits in reducing cooling loads and optimising thermal control system operations. They align with increasingly stringent global logistics energy efficiency standards and have broad promotion potential. Representative application cases include:

- Case 1 – Temperature Control Optimisation Project for Container Transport in Dubai: An international shipping supplier in Dubai, UAE, applied radiative cooling materials to the exterior of cold chain containers. The surface temperature of the containers dropped by up to 14°C, and the internal temperature decreased by 7.7°C, significantly reducing the operational cost of the refrigeration system and providing a replicable model for energy-saving in high-temperature region cold chain transportation.
- Case 2 – Cooling and Energy-Saving Project for City Buses in Hong Kong: In a city bus project in Hong Kong, radiative cooling materials were applied to the roof and exterior surfaces of the vehicles, achieving a surface temperature reduction of up to 12.4°C and an interior temperature drop of 4.6°C, reducing total air conditioning energy consumption by approximately 26% while effectively improving passenger thermal comfort and enhancing vehicle operational efficiency.





#### 4). Industrial and Manufacturing Facilities

In high-temperature industrial sites, especially production plants and large storage tank systems in industries such as chemicals, metallurgy, and energy processing, surface thermal management is a critical element for ensuring equipment operational safety and stability. Electricity-free passive radiative cooling materials can serve as auxiliary cooling solutions under high-temperature working conditions. They are widely used on equipment enclosures, tank bodies, process pipelines, and shading structures to effectively lower surface temperatures, relieve thermal fatigue effects, extend equipment service life, and to some extent, optimise working conditions for personnel, reduce ventilation and cooling system loads, and support the coordinated achievement of safety, energy-saving, and emission reduction goals in industrial systems. Representative application cases include:

- **Case 1 – Surface Renovation Project of Sludge Tanks by the Drainage Services Department in Hong Kong:** At a sludge treatment facility managed by Hong Kong's Drainage Services Department, applying radiative cooling coatings to the tank surfaces achieved an external temperature reduction of up to 33°C. As a result of the significant temperature drop, total exhaust gas emissions were effectively controlled, with a measured emission suppression rate of 59.6%, delivering both temperature control and environmental benefits.
- **Case 2 – Energy-Saving Project for Storage Tanks in an Organic Chemical Plant in Wuhan:** A chemical enterprise in Wuhan applied radiative cooling materials to the external surface of an epichlorohydrin storage tank. The tank's surface temperature dropped by 8°C throughout the day, and the internal liquid temperature decreased by 9°C, significantly improving thermal stability and safety, while reducing the operating cost of the cooling system by nearly 60%, showing high economic and operational value under high-temperature continuous operation conditions.

#### 5). Agricultural and Outdoor Work Scenarios

In agricultural facilities, temporary work sites, and outdoor high-temperature labour environments, electricity-free passive radiative cooling materials can be applied to greenhouse roofs, work tents, shading structures, and surfaces of personal protective equipment to effectively mitigate the heat buildup risks caused by direct sunlight. Especially in hot and humid southern regions or during intensive farming seasons, this technology helps stabilise internal greenhouse temperatures, reduce crop heat stress risks, and provide some level of body temperature regulation for frontline workers. Beyond crop cultivation, these materials can also be applicable in livestock farming to improve facility environments and enhance comfort for both animals and workers, thereby increasing survival and yield rates. In promoting the climate adaptability of agricultural and farming facilities, ensuring agricultural productivity, and supporting safe operations, these materials offer strong practical value. A representative application case includes:

- **Representative Case – Temperature Control Retrofit Project for Grain Storage in Henan Agricultural Industrial Park:** In a grain industrial park in Henan Province, radiative cooling coatings were applied to the exterior of grain storage facilities. As a result, the tank surface temperature was reduced by up to 30.9°C, and internal temperatures dropped by 2–5°C, effectively stabilising the grain storage environment. This also reduced maintenance and energy costs by about 25%, providing a low-cost and highly reliable thermal control solution for agricultural storage systems at the production site.

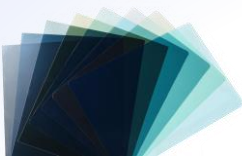




### 3.3.4 Representative Case Studies

#### Case 1: Electricity-Free Passive Radiative Cooling Film - i2Film

Glass curtain wall of a restaurant at a cruise terminal in Hong Kong: Two types of electricity-free cooling films were applied to approximately 320 square metres of café glass curtain walls, significantly reducing heat gain and lowering energy consumption.



##### Glass curtain wall of a restaurant at a cruise terminal in Hong Kong

—Two types of electricity-free cooling films (i2Film) applied to approximately 320 square metres of café glass curtain wall

September 2023

#### Energy Efficiency and Economic Calculations

##### Reduction in Lux levels leads to heat reduction

- Under standard sunny conditions, the baseline light intensity measured at the glass entrance was 6,910 Lux. The two types of iFilm respectively reduced Lux levels to a range between 1,190–1,450 and 490–630.
- For solar heat measurement, 1 Lux = 0.0081 watts/square metre.

##### Estimated air conditioning electricity cost savings

- Based on measurement data, the expected energy savings of the two types of i2Film are 137.35 and 149.74 kWh/square metre/year respectively.
- At an electricity cost of HK\$1.638/kWh, the total annual electricity savings amount to approximately HK\$74,000.

##### Cooling Performance and Economic Value

- The cooling performance of electricity-free cooling films does not degrade in the first 5 years. According to ageing test results, starting from year 5, cooling effectiveness decreases by 3% annually, maintaining 85% efficiency by year 10.
- The investment payback period is 2.66 years.



Data source: i2COOL



Case 2: Electricity-Free Passive Radiative Cooling - i2Coating

Rooftop project of an equipment room in a residential compound in Shenzhen: Electricity-free cooling coating was applied to approximately 100 square metres of rooftop surface, demonstrating effective thermal insulation by blocking outdoor heat transfer to the interior and significantly reducing external heat gain.



Rooftop project of an equipment room in a residential compound in Shenzhen

—Electricity-free cooling coating (i2Coating) applied to approximately 100 square metres of building rooftop

October 2024

Energy Efficiency and Economic Calculations

Comparison of electricity usage in the equipment room

- A comparison of daily power consumption before and after application shows a significant reduction in air conditioning electricity usage after the electricity-free cooling coating was applied.

Electricity Savings Calculation

|  |       |
|--|-------|
| Before application (Aug 24–28)<br>Average Daily AC Electricity<br>Consumption (kWh)    | 94.80 |
| After application (Aug 29–Oct 27)<br>Average Daily AC Electricity<br>Consumption (kWh) | 66.80 |
| Average daily electricity savings<br>(kWh)   | 28.00 |
| Average daily electricity savings<br>rate (%)  | 29.54 |

Cooling and Economic Results

- The i2Coating layer provides strong resistance against outdoor heat transmission into indoor spaces. **It reduces heat transfer by up to 8.5°C, and effectively lowers indoor air temperature, with a maximum reduction of 3.7°C**
- The average daily electricity savings rate for the equipment room reached 29.56%, equating to 0.29 kWh of electricity saved per square metre per day, and **approximately RMB 0.2 saved per square metre per day**
- **The project’s return on investment (ROI) is approximately 2.71 years**



Data source: i2COOL



Case 3: Electricity-Free Passive Radiative Cooling - i2Coating

Application on Chemical Storage Tank by an Organic Industry Company in Wuhan: An innovative solution to reduce the temperature of raw materials stored in chemical tanks. The solution effectively reduced the internal temperature of the chemical medium (epichlorohydrin), enhanced operational safety, and reduced water consumption by minimising the need for sprinkler-based cooling systems.



Application on Chemical Storage Tank by an Organic Industry Company in Wuhan

—An innovative solution for lowering the temperature of raw materials in chemical storage tanks

September 2023

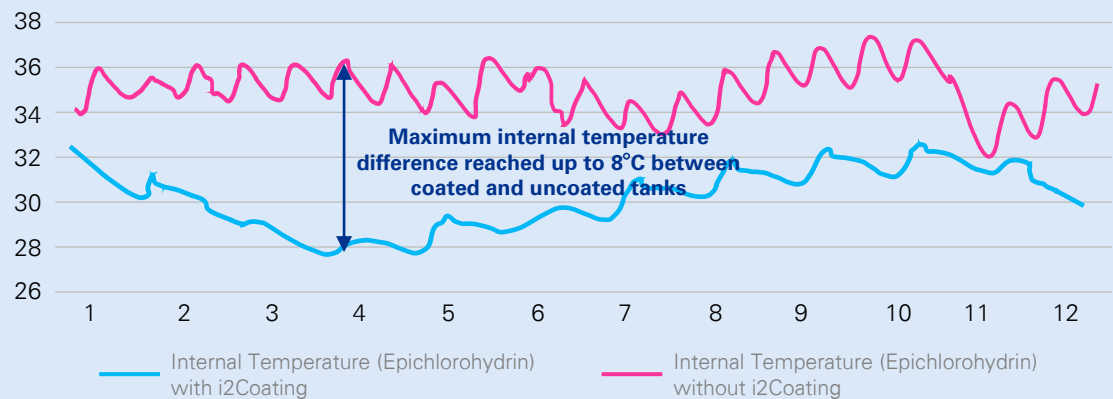
Energy Efficiency and Economic Calculations

Temperature comparison before and after coating

- After applying the radiative cooling coating to an epichlorohydrin (ECH) storage tank, the outer surface temperature of the tank was recorded at 28°C—lower than the ambient temperature
- The average daytime temperature inside the tank dropped by approximately 6°C. Even without activating the sprinkler system, the chemical medium inside the tank showed significant temperature reduction, enhancing tank safety and saving water resources

|                                | Temperature Comparison (Daytime) Before Coating | Temperature Comparison (Daytime) After Coating |
|--------------------------------|---|--|
|                                | Sprinkler Off: 43°C<br>Sprinkler On: 30°C       | Sprinkler Off: 28°C                            |
| Tank outer surface temperature |   |  |
| Ground surface temperature     | 52°C  | 53°C   |
| Outdoor ambient temperature    | 34°C  | 34°C   |

DCS System Data – Internal Temperature of Epichlorohydrin



Data source: i2COOL



## Case 4: Electricity-Free Passive Radiative Cooling - i2Coating

**Feed Storage Tank Project at a Livestock Farm in Shaanxi:** A comprehensive solution for reducing both external surface and internal temperatures of feed storage tanks. The project significantly lowered the average surface temperature of the tanks, extending feed storage duration while reducing cooling energy consumption and costs.



### Feed Storage Tank Project at a Livestock Farm in Shaanxi

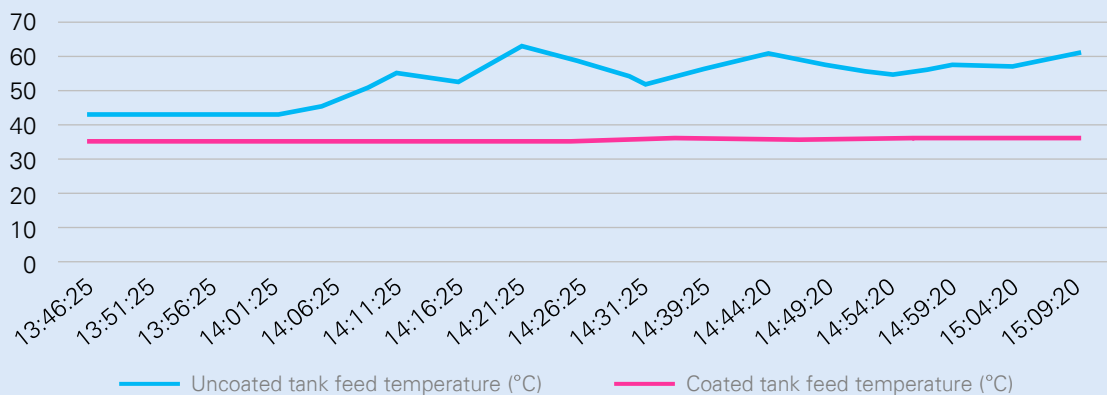
—Cooling solution for the external surface and interior of feed storage tanks  
July 2024

## Energy Efficiency and Economic Calculations

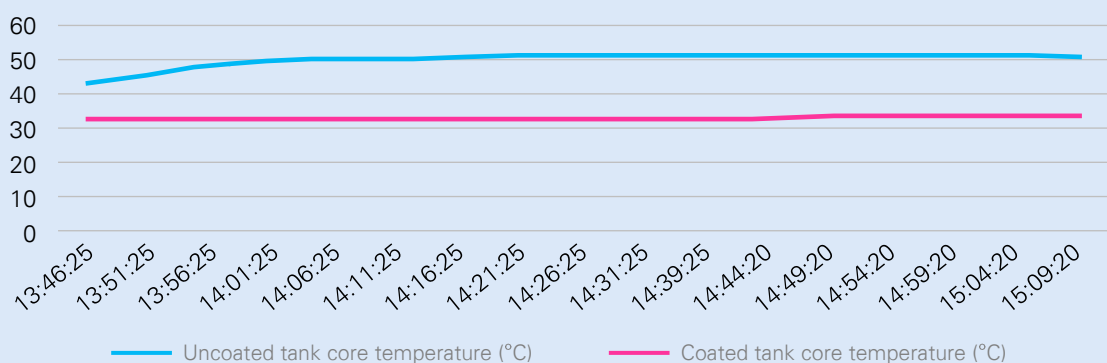
### Temperature comparison before and after coating

- For a 1.5-metre coated tank, **the average core temperature was 35.5°C, compared to 52.8°C in the uncoated tank—a reduction of 17.3°C, representing a 32.8% decrease**
- For a 4.5-metre coated tank, **the average core temperature was 32.4°C, compared to 49.7°C in the uncoated tank—a reduction of 17.2°C, or 34.6%**
- The maximum internal temperature reduction reached 18.8°C, while the maximum external surface temperature reduction reached 24.3°C

### 1.5m Tank Core Temperature



### 4.5m Tank Core Temperature



Data source: i2COOL

These case studies highlight the significant cooling benefits and cost-control value of electricity-free passive radiative cooling products in applications with clear temperature control demands, limited access to air conditioning, or high energy sensitivity. With their low maintenance requirements and high adaptability, these solutions are well-suited for high thermal load scenarios across urban buildings, industrial storage and transportation, and agricultural production—offering both improved energy efficiency and reduced operational risks.



# 04

## Market Opportunities and Business Value Analysis



Against the backdrop of growing attention to low-carbon energy systems and urban operational resilience, electricity-free passive radiative cooling is emerging as a frontier technology at the intersection of materials science, thermal management engineering, and sustainable architecture, gradually revealing its unique market value. With product performance becoming increasingly stable and application scenarios continuously expanding, the industry has shifted from the 'experimental validation' phase to the stage of 'scenario deployment and value realisation', laying the foundational conditions for broader market penetration.

As one of the fastest-growing segments in global energy consumption, cooling has a significant impact on energy security and environmental governance due to its energy cost, carbon intensity, and system stability. In light of traditional cooling systems still facing efficiency bottlenecks, refrigerant replacement pressure, and application boundary constraints, the passive cooling pathway characterised by 'zero energy consumption, low maintenance, and scalable deployment' offers new solutions for building energy efficiency, industrial cooling, and infrastructure thermal management.

This chapter starts from the structural demand of global and Chinese markets to analyze the penetration opportunities of electricity-free passive radiative cooling technologies across different regions, industries, and scenarios. It explores typical cooperation mechanisms and promotion pathways in current commercialisation efforts and outlines future trends in product functionality, process engineering, and system integration. By combining market potential estimation with feedback from actual projects, the chapter presents a roadmap for transitioning from material-based products to platform-based solutions.

## 4.1 Development Trends of Promotion Pathways and Cooperation Models

The commercialisation pathway of electricity-free passive radiative cooling technologies is continuously evolving as product maturity increases and application needs expand. The market is shifting from early-stage promotion models relying on policy pilots and demonstration projects to multi-channel, sector-specific, and cross-regional scaled deployment. Significant differences in promotion mechanisms, cooperation models, and procurement decision logic across application fields have shaped a multi-level, multi-tempo industrial synergy landscape.

### 1). Policy-Driven Initiatives and Demonstration Projects

Government-led public building retrofits, urban renewal programmes, and near-zero energy demonstration projects serve as important starting points for the early deployment of such new energy-saving materials. These projects are typically guided by energy performance targets, emphasising long-term operational results, alignment with green building standards, and the role of policy incentives in improving cost structures.

Local governments and state-owned platform companies often collaborate with technology providers through pilot programmes, dedicated funding support, or centralised procurement. These collaborations promote product deployment in low-carbon buildings such as schools, hospitals, office buildings, subsidised housing, and transitional shelters. In some regions, such products are included in green building material catalogues or government subsidy lists, creating strong policy synergy for urban thermal environment management and green park development.



## 2). System Solution Partnerships Driven by Industry Clients

In sectors such as industrial manufacturing, energy, transportation, and logistics, application scenarios present direct demands for improved thermal control, energy efficiency, and operational safety. These demands drive rapid product adoption through B2B client cooperation. Such partnerships are typically based on a 'problem-solving' sales logic, focusing on the product's actual benefits in equipment cooling, energy optimisation, and thermal environment management.

Cooperation models are often scenario-specific system integrations involving general contractors, equipment manufacturers, O&M service providers, and end-users. Companies are expected to possess capabilities for 'material-to-solution' technology translation and to deliver comprehensive services including construction guidance, temperature control simulations, energy-saving assessments, and payback period analysis. In high-temperature load scenarios such as energy storage, data centers, power communications, and new energy bases, trends towards batch procurement and centralised deployment are gradually forming.

## 3). Lightweight Product Expansion and Multi-Channel Exploration

As product materials become lighter and forms more diverse, some passive cooling products are starting to extend into the personal user market, particularly in consumer domains such as functional textiles, outdoor gear, and shading materials. Although still in an early stage and lacking a standardised market scale, this pathway contributes significantly to brand exposure and public awareness.

By partnering with retail channels, design brands, or nonprofit organisations, and launching joint marketing campaigns around themes such as 'personal thermal comfort', 'low-carbon lifestyles', and 'green consumption', companies can enhance user acceptance while building greater social influence and scenario expansion capabilities for their technology brands.

## 4). Building Diverse Collaboration Mechanisms and a Closed Commercial Loop

Overall, electricity-free passive radiative cooling technologies are undergoing a transformation from point-based procurement to platform-based collaboration, driving companies to evolve from material suppliers to system solution providers. Typical cooperation mechanisms include:



**Joint Demonstration Projects:** Enterprises co-develop pilot projects with industrial park platforms, real estate developers, and architectural design institutes, accumulating showcase projects and data validation.



**Scenario-Based Alliances:** Collaborate with end-user enterprises (e.g., photovoltaic, energy, cold-chain leaders) to conduct product adaptation testing, enabling co-development of standards and iterative optimisation.



**Green Finance Integration:** Link energy-saving assessment models to green credit and green bond programmes to access complementary financing or policy incentive support.



**Channel Co-Development:** Work with material distributors, e-commerce platforms for building materials, and integrated decoration providers to jointly develop the mid-market, enhancing coverage efficiency and channel flexibility.

Looking ahead, as policy systems become clearer and standards increasingly refined, cross-enterprise collaboration will drive the emergence of new ecosystem models in areas such as product standardisation, energy-saving performance evaluation, and carbon asset accounting—laying the groundwork for the broad-based expansion of passive cooling technologies and enabling a stable commercial closed loop.



## 4.2 Evolution Trends of Passive Cooling Technologies and Products

As an emerging technology system that achieves cooling by harnessing natural energy flow pathways, electricity-free passive radiative cooling remains in continuous evolution in terms of performance iteration, structural optimisation, and application extension. Looking ahead, with advancements in materials science, manufacturing processes, architectural integration, and system integration capabilities, the industry's development is expected to follow three major trends: multi-dimensional convergence, platform-oriented advancement, and deepened engineering adaptation.

### 1). Enhanced Material Performance and Environmental Adaptability

The core functionality of electricity-free passive radiative cooling materials relies on a synergistic mechanism of high solar reflectivity and high mid-infrared emissivity. At the material level, future products will further evolve towards ultra-high reflectivity (>97%), broadband emission capability, and all-weather adaptability. Current mainstream materials are primarily based on polymer-inorganic particle composites or high-performance ceramic systems, which offer a certain degree of weather resistance and thermal stability, yet still face challenges such as performance degradation under extreme climates, prolonged UV exposure, or mechanical stress.

In the next stage, new material systems with self-healing functionality, flexible compatibility, and recyclability are expected to become breakthrough points. Innovative pathways such as polymer microstructure alignment, bio-inspired optical structures resembling hair, and functional gradient interfaces are showing promising results in laboratory research and are expected to achieve engineering readiness within 3–5 years. At the same time, exploration into diversified colour systems, optically neutral appearances, and transparency control will also enhance the technology's penetration into consumer-level applications.

### 2). Product Forms Evolving Towards Systemisation and Modularisation

Early passive cooling products primarily existed in the form of coatings, films, and bricks, relying on surface treatment deployment for temperature reduction. As the market matures and customer needs diversify, product forms are rapidly evolving towards pre-integrated modules, functional componentised elements, and system-level interface materials. Examples include integrated roofing modules, embedded envelope panels, and equipment-level thermal control kits, all of which enable seamless assembly during construction, enhancing installation efficiency and product lifespan. Furthermore, these forms allow linkage with smart energy systems and intelligent building control systems, providing interface conditions for data acquisition, temperature regulation, and energy-saving evaluation.

This trend requires companies to move beyond merely possessing material R&D and production capabilities, and to establish comprehensive engineering service capabilities such as solution delivery, system interfacing, and standards development—truly entering the stage of being a 'solution-based product provider'.

### 3). Expansion of Application Boundaries and Strengthened Cross-Sector Integration

The application boundary of electricity-free passive radiative cooling is expanding from 'surface materials' towards 'system-level thermal management'. In the building sector, the technology is expected to form synergistic solutions with active energy-saving systems such as natural ventilation, shading devices, and smart façades. In industrial facilities, it can complement energy storage management, cooling systems, and emergency thermal control. In transportation and logistics, it may be co-optimised with new energy power systems and cold chain control systems to build multi-tiered thermal regulation capabilities.

Meanwhile, certain products are extending into lightweight scenarios such as textiles, outdoor consumer goods, and smart hardware, empowering emerging application markets through cross-sector collaboration. Integration with functional apparel, eco-friendly consumer products, and mobile energy devices is giving rise to new concept scenarios such as 'wearable cooling' and 'mobile temperature control', further increasing user engagement and market penetration. Under this trend, inter-enterprise industrial collaboration, standard co-development, and ecosystem partnerships will become mainstream development models. Centered around the combined value proposition of 'thermal control + cooling + materials + systems', the industry is expected to evolve towards a hybrid innovation model composed of material platforms, product systems, and scenario ecosystems.



## 4.3 Challenges and Recommended Responses

Although electricity-free passive radiative cooling technology is gaining increasing attention across policy, market, and investment dimensions, it still faces a series of systemic challenges in its path towards scaled application and industrial maturity. These issues are concentrated in four key areas: market awareness, supply chain capacity, standards system, and commercial mechanisms. Systematic responses are urgently needed, driven by industry consensus, collaborative mechanisms, and policy guidance.

### 1). Insufficient Market Awareness Restricts Promotion Speed

As a relatively new thermal management technology, radiative cooling materials still suffer from low awareness in end-user markets. Most users, design institutes, and even procurement parties often mistake it for traditional reflective coatings or thermal insulation materials, overlooking its core cooling mechanism based on mid-infrared radiation. This conceptual misunderstanding directly weakens the material's influence in project evaluation, material selection, and engineering integration, thereby limiting promotion efficiency and user acceptance.

The industry should enhance market education by shifting from 'material performance' to 'system-level thermal management capabilities'. By leveraging typical application cases and quantifiable cooling data, and through exhibitions, industry forums, and procurement guides, a clear and accurate understanding of the material's technology should be established. Meanwhile, its voice in standard systems related to green buildings, industrial energy conservation, and low-carbon transportation should be strengthened, positioning it not as a 'specialty material' but as a 'solution'.

### 2). Immature Supply Chain Limits Large-Scale Delivery Capabilities

The industry is currently in the transition from pilot-scale to mass production. Uncertainties exist in various aspects, including the sourcing of raw materials for the core functional layer, the stability of manufacturing processes, and the construction adaptability of different product forms (coatings, rolls, films). In particular, under complex conditions such as high salinity, humidity, or mechanical stress, the consistency and durability verification systems of materials remain underdeveloped, which affects their delivery performance in harsh environments and diminishes customer confidence.

It is recommended to establish a three-in-one compatibility and validation system encompassing 'core materials – process routes – application scenarios'. Upstream material suppliers should collaborate with midstream engineering integrators and downstream users to conduct long-term testing across multiple climate zones and operating conditions, while promoting the development of multi-dimensional standard indicators covering physical properties, weather resistance, and constructability. Industry-level public testing platforms and standard demonstration projects should also be encouraged to improve transparency and reliability in delivery.

### 3). Absence of Standard Systems Hinders Policy Integration and Engineering Conversion

At present, there is a lack of unified technical standards and evaluation frameworks specifically for electricity-free radiative cooling materials. In areas such as performance testing methods, energy-saving effect measurement, construction specifications, and product classification, the industry largely relies on 'corporate standards' or analogous methods. This makes it difficult for such materials to be effectively integrated into green building rating systems, financial subsidy mechanisms, or carbon emission accounting systems, thereby reducing their transformation efficiency under policy-driven scenarios.

Efforts should begin with industry associations, research institutions, and key demonstration projects to promote the development of a systematic evaluation framework. This should include multi-dimensional indicators such as emissivity, reflectivity, cooling capability, lifecycle benefits, and construction adaptability. In conjunction with policy application scenarios such as green buildings, green construction sites, and smart parks, the industry should explore a 'pilot project-driven guideline implementation' path, gradually establishing linkage mechanisms with policy tools like fiscal incentives, carbon trading, and green finance.



#### 4). Unclear Business Models and Lack of Financing and Value-Sharing Mechanisms

Currently, applications of this technology mostly take the form of 'one-time material purchases' or 'customised integrated solutions', without establishing commercial monetisation models that match its 'ongoing energy-saving benefits'. For instance, end-users struggle to monetise energy savings, investors lack return-on-investment models, and ESG funds cannot accurately quantify carbon reduction contributions, all of which reduce the willingness of financial capital to participate.

It is recommended to explore integrating passive cooling materials into performance-guaranteed service systems, enabling benefit-sharing with project operators through quantifiable energy-saving models. At the same time, carbon benefit metrics should be established in collaboration with green certification bodies and financial institutions, granting the material clear ESG investment attributes and completing the value loop from energy-saving technology to green assets.

Overall, electricity-free passive radiative cooling materials are at a critical stage of transitioning from 'frontier validation' to 'system implementation'. To truly shift from policy-driven to market-driven growth, the industry must persistently strengthen efforts across awareness consensus, standard development, supply chain collaboration, and business model innovation. Only by building a multi-party collaborative system that combines technical depth with ecosystem flexibility can this new technological pathway achieve large-scale application and long-term sustainable value realisation across broader scenarios.





## 4.4 Collaborative Initiatives and Ecosystem Co-Development Pathways

The promotion and application of electricity-free passive radiative cooling materials inherently involve cross-industry and interdisciplinary collaboration, spanning materials science, system integration, architectural and industrial design, and green finance. To further accelerate the commercialisation process and foster a healthy industrial ecosystem, it is essential to establish a more open, efficient, and mutually beneficial collaborative framework through multi-stakeholder cooperation.

It is recommended to build a cooperative path guided by standard co-development, scenario co-creation, outcome sharing, and capital synergy, in alignment with industry development trends:



Looking ahead, as green transitions and urban renewal accelerate across regions, passive cooling materials are expected to gain ecosystem-level deployment opportunities in key areas such as energy-efficient buildings, smart campuses, green transportation, and eco-industrial development. The industry must work towards building a shared understanding among stakeholders and fostering an open, collaborative, and innovative ecosystem to elevate these technologies from “low-carbon materials” to “system-level solutions” with broad and sustainable impact.



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