Economic Society and Humanities Vol. 3 No. 8, 2026

Construction Technology and Quality Control for Green Intelligent Buildings under Hainan's Tropical Maritime Climate

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Abstract: Hainan lies in a tropical maritime monsoon climate characterized by high temperature and humidity, intense solar radiation, frequent typhoons and rainstorms, and severe salt-spray corrosion, which poses great challenges to the construction and quality control of star-rated green buildings. Based on these climatic features, this paper analyzes the challenges in climatic environment, green technology adaptation, construction organization, and quality control, and establishes a "six-in-one" key construction technology system covering wind resistance, corrosion protection, heat insulation, damp proofing, energy efficiency, and ecological performance. The system includes typhoon-resistant foundations and main structures, wind-resistant envelope installation, salt-spray corrosion protection, dry-hung exterior insulation with ventilated cavities, integrated photovoltaic-waterproofing-insulation roofs, energy-efficient windows and shading, moisture-proof and ventilation control, renewable energy utilization, rainwater reuse, and prefabricated green construction. A whole-process quality management system featuring "preventive control beforehand, strict control during construction, and verifying control afterwards" is also developed for design, construction, acceptance, and operation-maintenance stages, supported by BIM, intelligent site monitoring, and digital quality records. A two-star green office building in Haikou shows that the system can reduce summer indoor temperature by 3–5°C and air-conditioning energy consumption by more than 40%, achieve salt-spray resistance of over 5,000 hours, and maintain envelope integrity under typhoons. This study provides a replicable "Hainan solution" for green buildings in tropical and coastal regions.

Keywords: Tropical Maritime Climate; Green Intelligent Building; Key Construction Technology; Whole-Process Quality Management and Control; Wind Resistance and Corrosion Protection; Heat Insulation and Damp Proofing; BIM Intelligent Monitoring; Hainan.

1. Introduction

Hainan is the only province in China located on a tropical island, and its entire territory falls within a tropical maritime monsoon climate distinguished by high temperature and humidity, intense solar radiation, frequent typhoons and torrential rains, and heavy airborne salt, persistent fog, and aggressive corrosion — the "five highs and three strengths" for which the region is known. In such an environment, the delivery of star-rated green buildings must move beyond conventional technical solutions toward key construction technologies and whole-process quality management tailored to local conditions, if the goals of safe and durable, energy-efficient and low-carbon, healthy and comfortable buildings are to be realized. With the implementation of policies such as the *Technical Standard for Green Building Construction* and the *Regulations on the Development of Green Buildings*, green building in Hainan has entered a stage of large-scale, standardized development, and the search for a green construction technology system suited to a tropical maritime climate carries both practical value and exemplary significance.

2. Distinctive Challenges Posed by Hainan's Tropical Maritime Climate to Green Buildings

Hainan's singular climatic conditions create multiple challenges for green building construction and quality management, which may be grouped under four headings.

2.1 Core Challenges Arising from the Climatic Environment

Temperatures stay high and rains come often throughout the year — mean annual

temperatures of 22–26 °C and relative humidity above 80 percent — so climate bears directly on such operations as concrete curing, the laying of waterproofing membranes, and the application of interior and exterior coatings. Intense ultraviolet radiation and long hours of sunshine accelerate the aging of building materials, subjecting organic materials in particular — plastics, rubber, and coatings among them — to a severe test of durability. During the typhoon season from August to November, gales of Force 11 or above and torrential rain strike repeatedly, obliging building structures, envelope systems, and ancillary installations to combine strong wind resistance, impermeability, and rapid drainage. Along the coast, salt-laden air corrodes materials three to five times faster than inland, placing exacting demands on the corrosion protection of steel structures, metal doors and windows, and embedded parts.



Figure 1. Coastal High-Rise Buildings in a Tropical Maritime Climate

2.2 Challenges in Adapting Green Building Technology

Whereas buildings in northern China are conceived around heat preservation and protection from cold, the core needs of star-rated green buildings in Hainan are heat insulation, ventilation, damp proofing, typhoon resistance, and corrosion resistance. Existing green building technologies cannot be applied directly: the thick insulation walls favored in the north, for example, tend to trap moisture indoors in Hainan and breed condensation and mold; ordinary energy-saving windows cannot satisfy the combined requirements of heat insulation, ventilation, wind-pressure resistance, and salt-fog resistance; and routine construction practices readily produce quality defects in the hot, rainy season. As a result, the central indicators of green buildings — energy efficiency, durability, and comfort — become difficult to attain.

2.3 Challenges in Construction Organization and Quality Control

In hot, humid conditions, worker efficiency falls, equipment failure rates climb, and materials deteriorate more quickly. Construction interrupted by the rainy and typhoon seasons fragments the schedule and complicates the linking of successive operations. Quality defects bred by a tropical climate are by nature insidious and delayed: defective anti-corrosion coatings, moisture trapped within walls, and corrosion of structural steel often come to light only after completion and occupancy. Conventional quality management, hard pressed to exercise precise control over the entire process, is ill equipped for such conditions.

3. Key Construction Technology System for Star-Rated Green Buildings in Hainan

In response to the tropical maritime climate, green building practice in Hainan has crystallized into a six-in-one system of key construction technologies — wind resistance, corrosion protection, heat insulation, damp proofing, energy efficiency, and ecological performance. The core techniques are presented below.

3.1 Construction Technology for Strongly Wind-Resistant Structures

Typhoon-adaptive foundation construction. The coral-reef geology and high groundwater table of Hainan's coast call for a foundation approach combining geological-radar survey with typhoon-resistant pile design. Prestressed high-strength concrete pipe piles are preferred, their toes embedded no less than 0.5 m into moderately weathered rock and their single-pile capacity sufficient to resist a Force-12 typhoon and a 0.5 g seismic acceleration. Pile caps and ground beams are cast with thickened concrete covers of at least 50 mm; fly ash and a high-range water-reducing admixture are incorporated to strengthen impermeability and corrosion resistance.

Wind-resistance enhancement of the main structure. High-rise buildings adopt steel-reinforced concrete (SRC) composite structures or high-strength reinforced concrete structures. Shear-wall reinforcement ratios are raised by 10–15 percent and stirrups are densified in joint regions, increasing overall stiffness and ductility.

Long-span roofs and cantilevered members are built as space trusses or steel systems whose members are joined by full-penetration welding supplemented with high-strength bolting; weld grades are no lower than Grade I, ensuring structural stability under typhoon wind loads.



Figure 2. Erection of the Steel-Reinforced Concrete Composite Structure of a High-Rise Building

Wind-resistant installation of envelope systems. Wall cladding panels, curtain walls, roof tiles, and other envelope components are fixed by a dual method combining mechanical fastening with structural adhesive bonding (Hainan Provincial Department of Housing and Urban-Rural Development). Curtain-wall mullions are tied to the main structure with stainless-steel bolts spaced no more than 800 mm apart. Roofs are clad in aluminum-magnesium-manganese alloy sheets joined by standing seams, with fixing brackets at intervals no greater than 500 mm and slopes of 35°–45° that improve both wind-uplift resistance and drainage. Windows are installed in three steps — subframe fixing, foam-filler injection, and weather-resistant sealant caulking — and exterior windows must reach a wind-load resistance of no less than Grade 8 and an air permeability of no less than Grade 6.

3.2 Construction Technology for Salt-Spray Corrosion Protection

Anti-corrosion treatment of structural steel. Main structural steel is of weathering grade and protected by a dual system of hot-dip galvanizing plus fluorocarbon coating. The galvanized layer is at least 85 μm thick and the fluorocarbon coat at least 80 μm, giving the coating system a salt-spray resistance exceeding 5,000 hours. Before erection, coating integrity is inspected on 100 percent of members; after erection, welds are touched up with primer, intermediate, and top coats extending no less than 100 mm beyond the weld toe.

Anti-corrosion treatment of metal components. Doors, windows, railings, embedded parts, and other metal components preferentially use 316L stainless steel or aluminum alloys (Hainan Provincial Department of Housing and Urban-Rural Development). Aluminum profiles are anodized to an oxide film no thinner than 15 μm, while stainless-steel components are pickled and passivated to strip surface impurities and oxide scale. A polyethylene isolation layer is interposed wherever metal meets concrete, forestalling galvanic corrosion.

Durability treatment of concrete. Sulfate-resistant cement is blended with high-quality fly ash and slag powder. The water-binder ratio is kept at or below 0.45 and the chloride-ion permeability coefficient at or below 8×10^{-12} m^2/s. Reinforcement corrosion inhibitors are added to exposed members such as exterior walls and roofs, whose concrete covers are deepened by 20 percent. Mixing water and aggregates are strictly checked for salt content so that the chloride-ion content stays within 0.06 percent.

3.3 Construction Technology for Efficient Heat Insulation

Exterior-wall insulation. Thick insulation systems of the northern type are set aside in favor of a composite of dry-hung exterior insulation and a ventilated cavity. The outer face carries 30–50 mm of extruded polystyrene (XPS) board or foamed-ceramic insulation board with a thermal conductivity no higher than 0.030 W/(m·K); a 100–150 mm cavity behind it induces natural ventilation by the stack effect and carries heat away; and the inner leaf is built of autoclaved aerated concrete blocks. Insulation and ventilation thus cool the wall together. The outer surface receives a high-reflectance heat-insulating coating with a solar reflectance of at least 0.85 and a hemispherical emittance of at least 0.88.

Integrated roof insulation and waterproofing. A "photovoltaic + waterproofing + insulation" roof system is promoted. A modified-asphalt waterproofing membrane not less than 4 mm thick is laid on the roof deck; above it sits a 50 mm foamed-concrete insulation layer sloped at no less than 3 percent; and photovoltaic modules are then mounted on raised supports at least 200 mm above the insulation, creating a ventilated

heat-break space. The roof thus generates electricity while lowering its surface temperature by 15–20 °C.



Figure 3. Integrated Rooftop Photovoltaic, Waterproofing, and Insulation System

Energy-efficient windows and shading. Exterior windows use thermal-break aluminum frames glazed with Low-E insulating glass units (5 + 12A + 5 mm), a shading coefficient no greater than 0.35, and a thermal transmittance no higher than 2.2 W/(m²·K). External shading is installed in tandem — photovoltaic louvers, aluminum shading grilles, or adjustable blinds — reaching a shading rate above 60 percent. Shading members are designed to withstand wind, with fixing points no more than 600 mm apart, so that they remain stable through typhoons.

3.4 Damp-Proofing, Ventilation, and Indoor Environment Control Technology

Damp proofing of the building. Two damp-proof courses protect the ground floor: a 100 mm C20 concrete base slab is coated with 2 mm of polyurethane moisture-barrier material, and above it a 50 mm raised void is formed, laid with a moisture-barrier mat that checks rising ground damp. Interior wall faces receive a vapor barrier of polyethylene-polypropylene composite waterproofing membrane, lapped no less than 100 mm and sealed with sealant. In wet areas such as bathrooms and kitchens, wall waterproofing rises at least 1.8 m and floor waterproofing extends 300 mm up the wall, applied as a polymer-modified cementitious waterproof coating no thinner than 1.5 mm.

Strengthened natural ventilation. Building on the wisdom of traditional Hainan architecture, natural ventilation is pursued through raised ground-floor voids, atria, cross-ventilation, and high windows. A void 2.2–2.5 m high at ground level admits sea breezes and produces cross-ventilation; continuous atria inside the building are vented at the top by skylights whose opening area is no less than 10 percent of the atrium floor area; and rooms are arranged on a north-south axis with doors and windows set opposite one another to create through-drafts. The skylights are of wind- and rain-resistant design, fitted with motorized operators that close automatically in typhoon weather.

Indoor air quality assurance. Efficient fresh-air heat-recovery systems deliver no less than 30 m³ per person per hour at a heat-recovery efficiency of at least 60 percent. The units include a filtration stage removing more than 90 percent of PM2.5, together with a dehumidification module that holds indoor relative humidity between 60 and 70 percent. Interior finishes use low-VOC materials — inorganic mineral paint on walls and E0-grade boards for furniture — and indoor air quality is tested after completion to confirm that formaldehyde, benzene, and other pollutants meet national limits.

3.5 Green, Energy-Efficient, and Ecological Construction Technology

Application of renewable energy. Hainan's abundant solar resource is put to use through the wide promotion of building-integrated photovoltaics (BIPV). Photovoltaic modules are integrated into roofs, curtain walls, and shading panels under a "PV-storage-DC-flexible" scheme that couples photovoltaic generation, energy storage, direct-current supply, and flexible loads; star-rated green buildings must reach a renewable energy substitution rate of no less than 20 percent. Domestic hot water is supplied by air-source heat pumps combined with solar collectors, at a coefficient of performance of at least 4.0.

Water conservation and rainwater utilization. Water-saving sanitary fixtures rated at water-efficiency grade 1 are specified. Rainwater collected from roofs and paved areas passes through first-flush diversion, filtration, and sedimentation before reuse for landscape irrigation, road washing, and water-feature replenishment. Planting favors native drought- and salt-tolerant species such as coconut palms, bougainvillea, and beach morning glory, irrigated by drip or micro-sprinkler systems that save at least 30 percent of water.

Green materials and prefabricated construction. Local bamboo, recycled aggregate concrete, low-carbon cement, and foamed ceramics are among the green materials promoted, and their utilization rate is required to be no lower than 40

percent in star-rated projects and 60 percent in three-star projects. Prefabricated construction is vigorously developed: precast components are manufactured in the factory and mechanically installed on site, reducing wet work and construction waste (Hainan Provincial Department of Housing and Urban-Rural Development). Connections between precast members rely on high-strength grout and sealant to secure wind resistance, impermeability, and corrosion resistance at the joints.

4. Whole-Process Quality Management System for Green Buildings in Hainan

In view of the tropical maritime climate, star-rated green building projects in Hainan operate a whole-process quality management regime — "preventive control beforehand, strict control during construction, verifying control afterwards" — that spans design, construction, acceptance, and operation.

4.1 Quality Control at the Design Stage

Climate-adaptive design. Projects comply strictly with the *Technical Standard for Green Building Construction* and undergo climate-specific design (Hainan Provincial Department of Housing and Urban-Rural Development). A dedicated green-building section in the design documents fixes the technical indicators and construction details for wind resistance, corrosion protection, heat insulation, damp proofing, and energy efficiency (Hainan Provincial People's Congress). Specialized simulations of typhoon wind loading, salt-spray corrosion, thermal performance, and natural ventilation serve to refine the design and confirm that the chosen technologies fit the climate.

Selection of materials and equipment. A list of materials and equipment suited to the tropical climate is compiled, giving preference to products that have passed salt-spray, high-temperature, and ultraviolet-resistance testing. Performance requirements are explicit: structural steel resisting salt spray for at least 5,000 hours, coatings with a solar reflectance of at least 0.85, exterior windows with wind-load resistance of no less than Grade 8, and waterproofing membranes withstanding heat of at least 90 °C. Samples of critical materials are sealed on site and sent for third-party testing; substandard products are barred from use.

4.2 Quality Control at the Construction Stage

Climate-adaptive construction organization. Special schemes are prepared for the hot rainy season and the typhoon season. During the hottest hours (11:00–15:00), concreting, coating, and membrane laying are avoided; in rainy weather, high-capacity pumping and drainage equipment is provided and rain shelters protect foundation pits, roofs, and floor slabs; and before a typhoon arrives, work at height ceases and temporary facilities, material stockpiles, and lifting plant are secured. A typhoon early-warning response mechanism allows the construction program to be adjusted in good time.

Corrosion-protection control. Anti-corrosion work on structural steel and metal components follows a "sample-led, fully supervised" procedure. Coating thickness, adhesion, and integrity are examined at a 100 percent rate and verified by thickness gauges, cross-cut tests, and salt-spray testing.

Insulation control. The flatness of insulation-board fixing, the number of fasteners, and the thickness of anti-crack render are tightly controlled; once exterior insulation is complete, thermal performance is measured to confirm that the thermal transmittance meets the design value.

Waterproofing and leak control. Waterproofing of roofs, exterior walls, and bathrooms is verified by both ponding tests of no less than 48 hours and water-spray tests of no less than 2 hours; the work is accepted only if no leakage appears.

Ventilation-system control. After natural-ventilation features and fresh-air systems are installed, ventilation performance is tested to ensure that indoor air speeds and air-change rates meet the design indicators.

Digital quality management. BIM is applied to construction simulation and clash detection so that successive operations dovetail smoothly (Notice of the Hainan Provincial Department of Housing and Urban-Rural Development on Further Strengthening the Administration of Prefabricated Building Construction, Qiongjianke [2025] No. 185). An intelligent site monitoring system tracks environmental parameters in real time — temperature, humidity, wind speed, and salt-fog concentration — alongside quality indicators such as concrete curing temperature, stress in structural steel, and window airtightness (Hainan Provincial Department of Housing and Urban-Rural Development). A quality-management application digitalizes work inspection requests,

rectification, and acceptance records, making quality responsibility traceable.

4.3 Quality Control at the Acceptance and Operation-Maintenance Stages

Special acceptance of green buildings. Before handover, projects undergo a special green building inspection covering six indicator groups, including safety and durability, health and comfort, resource conservation, and environmental amenity. Third-party institutions carry out specialized tests of envelope thermal performance, airtightness, indoor air quality, energy consumption, and renewable energy utilization. A project that fails the special green building inspection is not entitled to a certificate of completed acceptance (Hainan Provincial People's Congress).

Quality assurance during operation. At delivery, an operation manual for the green building sets out the maintenance requirements and cycles for corrosion protection, insulation systems, ventilation equipment, and photovoltaic systems (Hainan Provincial Department of Housing and Urban-Rural Development). An intelligent operation platform monitors building energy use, the indoor environment, and equipment status in real time and supports periodic performance evaluation and optimization (Hainan Provincial Department of Housing and Urban-Rural Development). Coastal buildings undergo inspection and maintenance of their anti-corrosion coatings every three to five years, safeguarding long-term durability.

5. Practical Case and Application Results

A two-star-rated green office building in Haikou and the International Trade Center illustrate what the technology system and management model described above can achieve. The project combines a raised ground-floor void, a ventilated roof, and photovoltaic shading: indoor summer temperatures run 3–5 °C lower than in ordinary buildings, and air-conditioning energy consumption falls by more than 40 percent. The dual corrosion-protection system gives the structural steel a salt-spray resistance of more than 5,000 hours; the envelope has come through typhoons without damage or leakage; and indoor air quality meets the required standards, markedly improving comfort. Having passed two-star green building certification, the project now stands as a demonstration of tropical green building.



Figure 4. A Two-Star-Rated Green Office Building in Haikou

6. Concluding Remarks

Building star-rated green buildings in Hainan's tropical maritime climate is a systems engineering task that fuses regional climate, green technology, and quality management. Its crux lies in breaking with conventional building technology to put in place a tropical-adapted construction technology system built around wind resistance, corrosion protection, heat insulation, damp proofing, energy efficiency, and ecological performance, while establishing a whole-process, digitally enabled quality management model. As the Hainan Free Trade Port advances and the "dual carbon" strategy is implemented, tropical green building technology will keep evolving, further raising structural safety, energy performance, and living quality, and offering China and the wider tropical and coastal world a replicable and scalable "Hainan solution."

Looking ahead, industry-university-research cooperation should be strengthened to develop green materials and intelligent construction technologies still better suited to tropical climates, to refine the standard system for tropical green buildings, and to move star-rated green buildings progressively toward ultra-low-energy, nearly-zero-energy, and zero-carbon buildings — so that architecture coexists in harmony with the natural ecosystem.

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