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Article

Maintenance of Facades in Public Infrastructures in Conditions of Low Rainfall

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Abstract

The maintenance of façades in public infrastructures located in low-rainfall regions represents a unique engineering and design challenge. Far from being beneficial, the scarcity of precipitation accelerates material degradation due to intense solar radiation, thermal fluctuations, and the persistent accumulation of pollution and dust particles, which are not naturally washed away. This context demands a comprehensive approach that combines advanced materials, adaptive designs, and systematic maintenance plans to ensure the durability, safety, and energy efficiency of public buildings. The methodology synthesizes current knowledge through a critical review of the indexed literature and recent case studies. The properties of cutting-edge materials such as Ultra-High-Performance Concrete (UHPC) and Glass Fiber Reinforced Concrete (GRC) are analyzed, along with resilient design strategies and non-destructive inspection protocols, assessing their suitability and performance in arid environments. The results and discussion of the findings reveal that UHPC, with a compressive strength 5-10 times greater than traditional concrete and extremely low porosity, virtually eliminates chloride penetration and thermal cycling degradation, reducing maintenance needs by up to 50% compared to conventional materials. GRC, meanwhile, emerges as a lightweight and versatile solution, with an estimated lifespan exceeding 60 years thanks to its high crack resistance. Strategically, the integration of adaptive façades that incorporate dynamic shading and natural ventilation has been shown to reduce the thermal load on buildings by 15-30%, significantly decreasing energy consumption. However, the effectiveness of these solutions depends on the implementation of rigorous and periodic inspection plans, ideally every 6-12 months under these conditions, to monitor contaminant accumulation and system performance. It is concluded that the synergy between high-performance materials, intelligent climate-adapted designs, and a proactive and predictive maintenance protocol is essential for the long-term sustainability of façades in public infrastructure in arid areas. This holistic approach not only mitigates the effects of adverse environmental conditions but also optimizes operational efficiency, ensuring the functional, aesthetic, and structural value of the built heritage.

Keywords: maintenance; public infrastructures; building

1. Introduction

Maintenance of facades in public infrastructures under conditions of low rainfall poses unique challenges due to the climatic factors that affect material durability and structural integrity. Facades act as the interface between the interior and exterior of buildings, playing a crucial role in protecting against external agents and contributing to a comfortable indoor environment [5]. However, in arid climates with low precipitation, the environmental stressors can lead to specific issues that require careful consideration during the maintenance process.

One of the primary challenges is the reduced presence of water, which, while beneficial in preventing issues like mold and moisture ingress, can lead to accelerated wear and tear of facade materials due to increased exposure to solar radiation and temperature fluctuations [7]. The lack of rainfall means that dirt, pollutants, and other particulates are less likely to be washed away naturally,

necessitating more frequent cleaning and upkeep to maintain the aesthetic and functional qualities of the façade [3].

Table 1. Comparison of Material Properties for Façades in Arid Conditions.

Material	Compressive Strength (MPa)	Estimated Useful Life (Years)	Maintenance Reduction	Thermal Conductivity (W/m·K)
Traditional Concrete	20-40	30-50	-	2.0-2.5
UHPC	150-250	75+	~50%	1.8-2.2
GRC	50-80	60+	~40%	1.2-1.5
Brick	20-60	50+	~30%	0.6-1.0

Note: Adapted from MDPI Buildings 14(2), 382 (2024) y MDPI Materials 15(12), 4131 (2022).

To manage these conditions effectively, a robust maintenance plan is essential. This plan should include detailed inspections, post inspection maintenance actions, and proactive maintenance strategies that take into account the unique environmental stresses faced in low rainfall areas [4]. Multi criteria approaches to prioritize maintenance actions are particularly useful, focusing on environmental impact, the extent of the required work, potential consequences of neglect, and safety requirements [4].

Furthermore, the selection of facade materials plays a significant role in ensuring resilience. Materials chosen for use in arid climates should be capable of withstanding prolonged exposure to sunlight and high temperatures without significant degradation [8]. This approach helps mitigate the effects of climate variations and contributes to the long term performance and durability of the façade [2].

Table 2. Impact of Adaptive Design Strategies on Energy Performance.

Design Strategy	Heat Gain Reduction	Improved Energy Efficiency	Ideal Application
Ventilated Facades	20-35%	10-20%	Hot and dry climates
Dynamic Shadows	25-50%	15-25%	Orientations with high solar radiation
Reflective Coatings	15-30%	5-15%	Large façade surfaces
Integrated vegetation (xerolandsaping)	10-25%	5-10%	Public spaces and squares

Note: Adapted from Arcadis ClimateScout® and Novatr (2023).

2. Methods

Effective Materials and Design Strategies for Facades

Effective materials and design strategies for facades in low rainfall areas emphasize durability, dust resistance, and minimal maintenance needs. The choice of materials is paramount in achieving these objectives. Brick is one such material, known for its classic appearance and low maintenance requirements [9]. Common bricks, made from clay, are cost effective and often used for structural purposes beneath exterior finishes [9].

Innovative facade materials like expanded polystyrene (EPS) cladding panels offer another solution. These panels are durable, lightweight, and energy efficient, providing protection against moisture infiltration while enhancing a building's thermal performance [11]. Although EPS panels are highly effective in humid climates, their benefits in low rainfall areas include reduced dust accumulation and ease of maintenance due to their smooth surface [11].

The importance of sustainability in facade materials cannot be overlooked. Opting for ecofriendly materials reduces the carbon footprint associated with manufacturing and transportation [12]. Sustainable facade materials not only ensure environmental responsibility but also contribute to the visual identity and functionality of a building [12].

Weather resistant facade solutions are also critical. With the global climate constantly changing, it is essential to use materials that can withstand elemental forces such as heavy rain, snow, wind, and temperature fluctuations [10]. Facades designed with these considerations in mind ensure both durability and aesthetic appeal, making them ideal for public infrastructures in low rainfall areas [10].

Systematic Maintenance Plans for Facades in Low Rainfall Regions Systematic maintenance plans for facades in low rainfall regions must take into account the unique environmental stressors and conditions of these areas to ensure the longevity and aesthetic appeal of buildings. One crucial aspect of such plans involves understanding and mitigating the impacts of climate change and extreme weather events. As the building's exterior envelope acts as the primary defense against harsh conditions, strategies need to be devised to adapt to climate variations and protect the structural integrity of the façade [13].

Key components of a maintenance plan tailored for low rainfall regions include strategies to minimize solar and heat gain, as well as mechanisms to facilitate natural ventilation, soil cooling, and radiant cooling. These passive design strategies are essential for creating energy efficient buildings that maintain a comfortable indoor temperature despite the arid external environment [14]. Given the minimal rainfall, special attention should also be given to the accumulation of dirt and environmental debris on the facades, which can lead to degradation if not regularly cleaned and maintained [15].

Glass facades, in particular, require diligent upkeep to sustain their appearance and functionality. In low rainfall areas, dust and grime can accumulate more rapidly due to the lack of natural cleansing by rain. Therefore, a systematic cleaning schedule must be established to prevent the buildup of contaminants that could compromise the structural integrity and aesthetic value of the glass [15].

Moreover, understanding the broader impacts of climate change on facade materials is vital. Temperature variations and extreme weather events can affect the durability of facade materials, necessitating the use of adaptive measures to mitigate these impacts [16]. This involves selecting materials that are resilient to temperature changes and implementing design solutions that enhance the facade's ability to withstand environmental stressors.

3. Results and Discussion

Benefits of Advanced Concrete Materials in Facade Construction

UltraHigh Performance Concrete (UHPC)

UltraHigh Performance Concrete (UHPC) is a significant advancement in concrete technology [21]. It offers superior properties compared to traditional concrete, making it a valuable option for various construction applications. UHPC boasts exceptional strength, exceeding traditional concrete by 5-10 times, allowing for thinner elements in structural design while maintaining load bearing capacity [21]. Additionally, UHPC offers remarkable durability, resisting cracking, freeze thaw cycles, and harsh chemicals, which translates to a longer lifespan for structures and potentially reduced maintenance needs [21].

Dr. Nemkumar (Nemy) Banthia, a University Killam Professor and Sr. Canada Research Chair at UBC Civil Engineering, has extensively explored the revolutionary potential of UHPC in construction [22]. In his latest publication, *Ultra High Performance Concrete: Design, Performance, and Applications*, Dr. Banthia discusses the unique properties of UHPC and its implications for sustainable urban development [22]. His research highlights the efficiency and performance benefits of UHPC, particularly in facade construction in environments with low rainfall, where the material's durability and longevity can significantly reduce maintenance requirements [22].

Glass Fibre Reinforced Concrete (GRC)

Glass fiber reinforced concrete (GFRC), also known as glassfibre reinforced concrete or GRC in British English, has become a prominent material in modern facade construction due to its advantageous properties, especially in environments with low rainfall [19]. This type of fiber reinforced concrete is composed of alkali resistant glass fibers that imbue the material with enhanced flexibility, plasticity, and high compressive strength, making it suitable for thin walled elements such as facade panels [19,20].

One of the primary benefits of GFRC in facade construction is its lightweight nature, which significantly reduces the load on the building structure and allows for innovative design solutions, including large artificial rocks and other architectural accents that would be impossible with traditional materials [18]. This characteristic is particularly beneficial in areas with low rainfall, where the reduced weight helps in maintaining the structural integrity over time, as it minimizes stress and potential damage due to environmental factors [18,20].

Furthermore, GFRC offers high durability and resistance to cracking, which is essential for maintaining facades in arid conditions. The material's flexibility allows it to withstand the thermal expansion and contraction cycles typical in such climates without compromising its structural integrity [17]. This durability is complemented by GFRC's aesthetic versatility; it can be molded into various shapes and finishes, providing architects the freedom to create detailed and visually appealing facades that meet both functional and design requirements [20].

Integration of Adaptive Facade Designs and Sustainable Practices

Adaptive Facade Designs

Adaptive facades play a critical role in the maintenance of public infrastructures, especially in areas with low rainfall. Facades serve as the interface between the interior and exterior of a building, protecting it from external agents and contributing significantly to creating comfortable environments [24]. In the context of low rainfall areas, adaptive facade designs are particularly valuable as they are capable of resisting dust and pollutants while enhancing energy efficiency.

The concept of resilience is central to adaptive facade designs. Resilience, in architecture, involves the capability of a structure to recover and adapt after facing adverse conditions. This includes the integration of materials and structures that can "learn" from their environment and continuously reinvent themselves to withstand various challenges [25]. Predicting potential scenarios, including

environmental conditions typical to low rainfall areas, is essential in designing facades that are not only resilient but also sustainable.

Climate responsive facade designs focus on adapting to local weather and climatic conditions to optimize energy efficiency and occupant comfort. This involves the use of innovative solutions such as solar panel facade systems and ventilated facade systems that address the specific challenges posed by varying weather conditions [27]. By considering factors such as seasonal variations and the particular climate characteristics of low rainfall areas, these designs can significantly improve the performance and durability of building exteriors.

Moreover, the green building movement has evolved into what can be termed “Green Building 2.0”, where dynamic, intelligent systems are integrated to create buildings that think, move, react, and adapt to real time conditions [28]. This next stage of green building involves adaptive facades that form an active relationship with their environment, enhancing the overall sustainability and resilience of public infrastructures.

Table 3. Recommended Frequency of Maintenance and Inspection Activities.

Activity	Recommended frequency (months)	Main Method	Critical parameter to be evaluated
General Visual Inspection	6-12	Digital photography, records	Dirt buildup, surface degradation
Deep Cleaning	12-24	Cleaning with low-pressure deionized water	Loss of reflectivity, clogging of systems
Non-Destructive Assessment (NDE)	24-48	Thermography, ultrasound	Internal fissures, detachment, residual moisture
Sealant & Gasket Review	18-36	Tactile and visual inspection	Loss of elasticity, cracks, disadhesion

Source: Adapted from ASCE Civil Engineering Source (2022) and Medium (2023).

4. Conclusions

Sustainable Architectural Practices for Energy Efficiency

Sustainable architectural practices in public infrastructures within low rainfall areas emphasize the integration of adaptive facade designs to enhance energy efficiency and environmental harmony. Vernacular construction technologies, refined over centuries through practical wisdom and countless trials and errors, provide a foundational understanding of creating highly efficient systems that are inherently adapted to local climates and resources [23]. These traditional methods offer critical insights into conserving heat with minimal energy, which is crucial for modern buildings aiming for sustainability.

Adaptive facades can play a pivotal role in such environments by not only resisting dust and pollutants but also by optimizing thermal performance. Facades designed with features such as dynamic shading devices, advanced glazing systems, and natural ventilation strategies can significantly reduce the reliance on mechanical heating and cooling systems. For instance, traditional passive cooling techniques like Persian wind towers and Arab mashrabiya have been instrumental in promoting passive cooling. Similarly, in cold climates, adaptive facade designs focus on heat retention and efficient space heating solutions, integrating modern innovations with time tested

practices [23]. These strategies collectively contribute to a reduced carbon footprint, lower operational costs, and improved indoor comfort in public infrastructures, making them an essential component of sustainable architectural practices in low rainfall areas.

Best Practices for Facade Inspections

Facade inspections play a crucial role in maintaining the safety, integrity, and aesthetic value of buildings, especially in regions with low rainfall. These inspections help proactively identify potential maintenance issues before they escalate into significant problems.

One of the best practices for facade inspections in dry climates is to utilize Nondestructive Evaluation (NDE) techniques. NDE methods help assess the properties of a building's facade without causing any damage, making it possible to determine the cause of distress conditions and to identify suitable remedial actions [29]. This practice is often implemented before initiating any repair or rehabilitation work, ensuring a thorough understanding of the facade's condition.

A comprehensive facade inspection process involves a detailed examination of the building's exterior to assess its condition and identify potential issues. The primary purpose of such inspections is to ensure safety, maintain the building's appearance, and comply with local building codes and regulations [30]. For buildings in low rainfall areas, specific considerations include monitoring for issues that might not be immediately apparent, such as the gradual degradation of materials due to prolonged exposure to sunlight and temperature fluctuations.

Design strategies for building facades in hot and dry climates should focus on passive cooling, natural ventilation, and the use of light-colored surfaces to reflect heat. Double glazing and shaded windows can also help in reducing thermal stress on facade materials [31]. Implementing these strategies can mitigate some of the maintenance challenges associated with low rainfall areas.

Regular facade inspections should follow a well-structured checklist that accounts for the unique needs of the building. This checklist may include monitoring waterproofing measures, checking the integrity of sealants, and assessing any repainting or refinishing work required for metals and other materials [33]. Continuous monitoring and timely interventions can prevent minor issues from becoming major repair projects.

Adherence to local laws and regulations, such as New York City's Local Law 11, can serve as a valuable framework for facade inspections. These laws mandate periodic inspections by qualified professionals and ensure that any identified deficiencies are promptly addressed [32]. While these regulations are designed to ensure public safety, they also emphasize the importance of regular maintenance in extending the lifespan of building facades.

Recent Advancements in Concrete Materials

Recent advancements in concrete materials have significantly enhanced the performance and durability of facades in public infrastructures, especially under low rainfall conditions. Two noteworthy innovations in this realm are Ultra High Performance Concrete (UHPC) and Glass Fibre Reinforced Concrete (GRC).

UHPC is characterized by its low water cement ratio, typically ranging from 0.20 to 0.25, which plays a critical role in achieving a compact and robust structure through hydration. This low ratio reduces capillary pores, enhances ductility, and prevents brittle collapse [35]. The material also boasts a high particle packing density, achieved through the utilization of fine binder materials. This high density minimizes water demand in the fresh mixture, thereby improving compressive strength and reducing brittleness [35].

To further address the unique challenges posed by low rainfall conditions, UHPC compositions include only fine aggregates such as natural sand, silica sand, recycled glass cullet, and quartz sand. Coarse aggregates are avoided as they can weaken the interfacial transition zone (ITZ) and consequently the structural integrity of the concrete [36]. Despite UHPC typically exhibiting lower workability due to the internal friction between concrete ingredients, it remains a preferred choice due to its superior mechanical properties and durability.

These advancements in UHPC not only enhance structural integrity but also contribute to aesthetic longevity in low rainfall areas. The minimized water absorption and porosity, along with resistance to chloride penetration, freezing and thawing, dry shrinkage, and creep, ensure that the concrete facades maintain their structural and aesthetic qualities over extended periods [36].

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