

Critical Review on Photocatalytic Polymer Nanocomposites for Indoor Air Purification in Hotels

Saurabh Tripathi^{1*}, Sidhanshu Rai²

Abstract

The indoor air quality has become a key measure of health, comfort, and customer satisfaction of a hospitality setting. The challenges that continually affect hotels especially because of volatile organic compounds (VOCs), particulate matter, and microbial pollutants that are present in cleaning agents, furnishing, and human activity. In this regard, the photocatalytic polymer nanocomposites are one of the sustainable and efficient means of purifying indoor air. These materials combine photocatalysts (titanium dioxide (TiO₂), zinc oxide (ZnO), or graphitic carbon nitride (g-C₃N₄)) with polymeric materials (such as polyethylene, polystyrene, or polymethyl methacrylate) to make lightweight, flexible, durable films that can decompose organic pollutants when irradiated with light. Exposure of the photocatalyst oxidant to UV or visible radiation leads to oxidation of detrimental molecules by reactive oxygen species into harmless end products like carbon dioxide and water. This paper highlights the preparation, structural characterization, and performance optimization of photocatalytic polymer nanocomposites designed to meet the needs of hotel settings in terms of morphology of their surface, dispersion of photocatalysts, light absorbing ability, and stability. Its application potential is also achieved in terms of the coating, air filters, wall paint, and textile treatment, which altogether help to keep the interiors hygienic, odorless, and energy-efficient. The incorporation of the above smart materials is in line with the concept of green hospitality, which minimizes the use of chemical air freshener and improves the occupant well being. Future research interests involve visible-light-active composites, hybrid photocatalysts and scalable fabrication methods to implement in the real world in hotels.

Keywords: Photocatalysis, polymer nanocomposites, indoor air purification, titanium dioxide, zinc oxide, volatile organic compounds, green hospitality, smart coatings, hotel environment, sustainable materials

INTRODUCTION

IAQ has emerged as a rather important topic of contemporary built environment in particular in the hospitality sector, including hotels where the level of customer satisfaction, cleanliness, and freshness are major factors in operational performance. The health hazards caused by poor IAQ include respiratory irritation, fatigue, and chronic illnesses in the long run due to volatile organic compounds

(VOCs), particulate matter (PM), carbon monoxide (CO), nitrogen oxides (NO_x), and microbial contaminants [13]. Hotels are considered unique in their architectural and operating characteristics due to closed spaces, artificial ventilation, use of chemicals in cleaning facilities and high turnover of the occupants which form a complex blend of air pollutants that are not easily handled through conventional clean up systems. Some of the traditional techniques, including mechanical filters, and activated carbon units, though effective in particulate and odor removal, are heavy energy-

*Author for Correspondence

Saurabh Tripathi

¹Research Scholar, School of Business Management, CSJM University, Kanpur, Uttar Pradesh, India

²Assistant professor, School of Business Management, CSJM University, Kanpur, Uttar Pradesh, India

Received Date: December 27, 2025

Accepted Date: January 20, 2026

Published Date: February 23, 2026

Citation: Saurabh Tripathi, Sidhanshu Rai. Critical Review on Photocatalytic Polymer Nanocomposites for Indoor Air Purification in Hotels. Journal of Polymer & Composites. 2026; 14(Special Issue 2): S527–S541p.

consumers, requiring regular maintenance, and may also be a source of secondary pollution themselves [4]. The increasing difficulty has prompted scholars to seek a sustainable, self-regenerative and energy-efficient solution like the photocatalytic polymer nanocomposites (PPNs)

Photocatalysis is an advanced oxidation reaction that is carried out by the activation of semiconductor materials in the presence of light to produce reactive oxygen species (ROS) such as hydroxyl radicals ($\bullet\text{OH}$) and superoxide ions (O_2^-). Photocatalysis is capable of breaking down a significant variety of organic and microbial pollutants into harmless by-products (such as CO_2 and H_2O) [8]. Some of the most common photocatalysts currently known include titanium dioxide (TiO_2), zinc oxide (ZnO), and graphitic carbon nitride ($\text{g-C}_3\text{N}_4$). These compounds have good oxidative potential, are chemically stable and not very toxic [9,10]. Dispersed into polymer matrices as polyethylene (PE), polystyrene (PS), polyvinyl alcohol (PVA), or polymethyl methacrylate (PMMA), these nanostructured photocatalysts give rise to hybrid materials that provide the flexibility, transparency, and mechanical strength of the polymer with the self-cleaning and antimicrobial capabilities of the photocatalysts [11]. The polymer is an assistive framework which allows the transmission of light and diffusion of pollutants and prevents aggregation or leaching of the active nanoparticles.

PPNs are especially attractive in the case of hotel settings. They can be used as either wall coats, air filters, curtain linings, window laminates or decorative panels unlike bulky purifiers which are difficult to blend in with the aesthetic design and still offer constant passive purifying of the air [12]. The working principle is simple and yet very efficient: when the photocatalyst nanoparticles integrated into the surface of polymer are exposed to ambient or artificial light, they produce ROS, which oxidize airborne VOCs, bacteria, and viruses. This technology does not only keep the air clean and odour free but also minimises the use of chemical air fresheners and cleaning agents, a move that is in line with the world trend of green hospitality and sustainable building technologies [13].

The source of light is also important in deciding photocatalytic activity. Whereas TiO_2 has a high activation in ultraviolet (UV) light, its functionality in the visible light, which predominates in the indoors, is poor. Thus, recent developments have dwelled on the modification of photocatalysts by doping (e.g. with nitrogen, carbon or metal, like silver, iron, etc.), by coupling with narrow-bandgap semiconductors, or by incorporating plasmonic nanoparticles to improve visible-light absorption [14,15]. Similarly, a series of hybrid nanostructures like $\text{TiO}_2\text{-ZnO}$, $\text{TiO}_2\text{-Ag}$, and $\text{g-C}_3\text{N}_4\text{-TiO}_2$ has been established to enhance the performance of charge separation, lower electron-hole recombination, and prolong the duration of photocatalysis at low-intensity lighting conditions eco-friendly hotel interiors usually experience [9].

The PPNs are designed in such a manner that they can be highly customized to the needs of the hotel. As an example, one can apply transparent PMMA-TiO_2 films on the windows in order to use natural daylight without sacrificing aesthetics. Composites of $\text{g-C}_3\text{N}_4$ nanosheets based on polyurethane can be used to produce a flexible coating on air-conditioning duct and furniture surfaces, and ZnO -impregnated PVA membranes can be used as antimicrobial air filters. The systems are silent, entail low maintenance, and in combination with the existing lighting systems, they consume little power [5,12]. Implementation of PPNs in hotel air systems also brings with it other advantages other than the reduction of pollutants. The existence of the antimicrobial effects of the photocatalytic surfaces assures the maintenance of hygiene in high-contact areas like lobbies, kitchen, restrooms and guest rooms. The released ROS in the process of photocatalysis destroys bacterial cell walls and denatures viral proteins, providing an effect of sterilization without using severe chemicals [11,13]. The attribute comes in especially handy during the aftermath of the pandemic, when microbial safety has become one of the major factors of customer confidence. In addition, these materials also help in saving energy since there is reduced use of HVAC filters and chemical purification cycles thus resulting to reduced operational costs and increased sustainability indices. PPN-based purification has both considerable environmental and economic advantages. These are composites that do not need consumables, cannot form secondary

waste and their lifecycle of operation is long and may even last more than five years under controlled conditions in the indoor environment [4,9]. The fact that these materials can be incorporated into the current infrastructures of hotels, including HVAC ducts, decorative panels, or curtains, provides a scalable and affordable route to the passive control of pollution. Moreover, polymer-based matrices can be used to make sure that the coating or films are lightweight, simple to produce, and are able to comply with complicated interior designs.

Scientifically, it is one of the greatest challenges to obtain homogeneous distribution of photocatalytic nanoparticles in the polymer phase. Due to agglomeration, the active surface area may be drastically lowered and block light penetration. Sol-gel synthesis, melt compounding, in situ polymerization and electrospinning techniques have been utilized to enhance homogeneity, interfaces between the polymer and photocatalyst [10,12]. Also, surface functionalization through silane coupling agent, plasma treatment or surfactant-aided blending improves compatibility and durability of the composites [13]. Regardless of the improvements, there are still some constraints. The degradation of polymer under a long-term exposure to UV-light conditions can lead to a decrease in optical transparency and structural strength, whereas the inadequate optical absorption at the visible wavelength still limits the efficiency in the hotel lighting background [14]. To solve these problems, it is necessary to continue the investigation of UV-shielded polymers, co-catalyst system, and multi-component composite that can absorb a wider range of light. Nanofabrication, including the creation of hierarchical micro-nano structures and photonic crystal coating, is enabling next-generation PPNs which are able to operate effectively under ambient lighting within the indoors [15]. To sum up, photocatalytic polymer nanocomposites are a game changer in IAM as far as the hospitality industry is concerned. They fit well inside hotel interiors, and they work passively in the presence of visible or artificial light, as well as, they degrade VOCs and microbial contaminants and preserve aesthetic value and energy consumption. With the global trend of hotels becoming eco-certified and going green, there are two real benefits to the use of PPNs; not only is it better to keep the guests healthy, but also to minimize the environmental impact. Further studies are needed in the area of the long-term field validation, development of the hybrid visible-light catalysts and incorporation with the intelligent building systems to make it possible to monitor the air quality in real-time and control dynamically the photocatalytic work [1].

RELATED WORKS

The application of photocatalytic polymer nanocomposites (PPNs) for indoor air purification represents a convergence of environmental science, nanotechnology, and sustainable design—an area that has evolved from material synthesis to real-world architectural integration. The literature reviewed below presents a synthesized view of the recent advances, mechanisms, material formulations, and deployment contexts relevant to hotel interiors, with emphasis on TiO₂-based nanocomposites, polymer–nanofiller integration strategies, visible-light activation, and sustainable applications in air purification. Early foundational work established the importance of nanomaterials in interior and architectural design. Anous [3] and Leydecker [18] discussed the aesthetic and functional benefits of nanomaterials in interior architecture, emphasizing their potential to integrate self-cleaning and antimicrobial properties into decorative surfaces. Al-Maliki [2] and Alhmoud [1] expanded this idea into hospital and hospitality contexts, linking nanomaterial sustainability with indoor environmental quality. These studies emphasized that air purification is not only a technological challenge but also a design concern requiring materials compatible with human comfort and health standards. From a photocatalytic material standpoint, TiO₂ remains the most widely researched catalyst. Athanasekou et al. [4] and Feroso et al. [8] highlighted TiO₂'s advanced oxidation potential, capable of degrading VOCs, NO_x, and organic particulates. However, its limitation to UV activation prompted research on visible-light-responsive systems. Gunti et al. [11] and Sewart et al. [31] provided reviews on doped TiO₂ and g-C₃N₄/TiO₂ heterojunctions, showing enhanced photocatalytic performance under indoor light. Sen et al. [32] further analyzed doping strategies—metallic, non-metallic, and co-doping approaches—to extend spectral response and improve charge separation efficiency, which is critical in low-irradiance hotel environments. Tables 1 and 2 collectively highlight the role of nanomaterials and

photocatalytic systems in enhancing indoor environmental quality and sustainable architectural design. Table 1 presents early studies demonstrating that nanostructured coatings and TiO₂-based polymer systems improve aesthetics, self-cleaning ability, and air quality, while Table 2 shows that advanced photocatalytic composites achieve high pollutant degradation efficiency (up to 95%) for VOCs, nicotine, and dyes. Material researchers have also explored polymer integration to enhance processability and flexibility. Chanklom et al. [5] developed polylactic acid (PLA)/TiO₂ composite films that demonstrated VOC degradation in confined spaces. Similarly, Ismayil and Varghese [15] fabricated silver-doped polyaniline–PVC films exhibiting dual photocatalytic and antibacterial properties, providing an ideal framework for hotel air filters or wall coatings. Yuan et al. [37] introduced g-C₃N₄-modified polyacrylonitrile fabrics with visible-light self-cleaning and water disinfection capabilities—demonstrating the potential of polymer-based fabrics in curtains or upholstery for hospitality use.

The practical application of photocatalysis for air purification was examined by Yu and Kim [36] and Han [12], who investigated heterogeneous photocatalytic oxidation (HPCO) systems for continuous degradation of VOCs indoors. Their findings established that photocatalysis can significantly reduce formaldehyde and benzene levels within enclosed environments. Cieślak et al. [6] corroborated these results by demonstrating that TiO₂-modified polypropylene fibers effectively decomposed nicotine, indicating a pathway for fabric-based purifiers suitable for hotel rooms or smoking areas. Table 1 presents an overview of early studies on nanomaterials in interior and architectural design, highlighting their role in improving aesthetics, self-cleaning behavior, and indoor air quality in hospitality environments. Table 2 summarizes the performance of photocatalytic systems evaluated for indoor air quality improvement, showing their pollutant degradation efficiency under different light sources and support materials. Table 3 outlines recent advances in polymer–nanoparticle fabrication and integration techniques, emphasizing how different synthesis methods enhance surface area, antibacterial activity, and purification performance.

Table 4 compares visible-light and hybrid photocatalytic systems, demonstrating the growing importance of advanced composites for efficient indoor air purification under practical lighting conditions.

Table 1. Summary of early studies on nanomaterials in interior and architectural design.

Study	Focus area	Material/system	Key findings	Application relevance
[3] Anous (2014)	Interior design integration	Nanostructured coatings	Enhanced aesthetics, self-cleaning	Interior walls, furniture
[2] Al-Maliki (2022)	Indoor environmental design	TiO ₂ in polymers	VOC and odor reduction	Sustainable interiors
[1] Alhmod (2024)	Healthcare/hospital context	Multifunctional nanomaterials	Improved IAQ and antimicrobial activity	Hotels, hospitals

Table 2. Photocatalytic systems evaluated for indoor air quality improvement.

Study	Photocatalyst	Support material	Target pollutant	Degradation efficiency (%)	Light type
[5] Chanklom et al. (2021)	TiO ₂	PLA	VOCs	92	UV-Visible
[6] Cieślak et al. (2017)	TiO ₂	Polypropylene	Nicotine	85	UV
[36] Yu & Kim (2013)	TiO ₂	Wall coating	Benzene, Toluene	80	UV
[31] Sewnet et al. (2022)	g-C ₃ N ₄ /TiO ₂	Composite film	Organic dyes	95	Visible

Table 3. Advances in polymer–nanoparticle fabrication and integration techniques.

Study	Fabrication method	Polymer used	Additive nanomaterial	Key feature
[30] Samadi & Moshfegh (2022)	Electrospinning	Polyacrylonitrile	TiO ₂ nanoparticles	High surface area films
[28] Pelaseyed et al. (2020)	Casting	PLGA	TiO ₂	Antibacterial + photocatalytic
[22] Lou et al. (2023)	Electrospinning	PLA	Halloysite nanotubes	Dual disinfection-purification

Table 4. Recent developments in visible-light and hybrid photocatalytic systems.

Study	Photocatalyst	Matrix	Light source	Efficiency (%)	Application potential
[7] Devi et al. (2019)	Ag/C nanocomposite	Polymer blend	Visible	90	Coatings, filters
[19] Liang et al. (2015)	CdS-triptycene polymer	Self-supporting	Visible	88	Textiles, curtains
[24] Mohamed et al. (2025)	TiO ₂ hybrid composites	Polymer matrix	LED	91	Interior coatings

Architectural and environmental studies such as those by Franzoni et al. [9], Nath et al. [25], and Wei et al. [35] investigated the incorporation of photocatalytic finishes into construction and building materials. These studies demonstrated that TiO₂-based coatings applied to walls and renders can significantly reduce ambient pollutant loads while retaining aesthetic compatibility. Papadaki et al. [27] and Puddu [29] emphasized the potential of TiO₂ nanocoatings for heritage structures and modern buildings alike, reflecting their adaptability for hotel retrofitting. Luengas et al. [23] and Luengas Muñoz [24] reviewed biofiltration–photocatalysis coupling systems, highlighting future prospects for integrating hybrid air-treatment units within HVAC frameworks.

In the realm of advanced polymer–nanoparticle synthesis, Samadi and Moshfegh [30] and Pelaseyed et al. [28] developed electrospun nanocomposite scaffolds and PLGA/TiO₂ films, respectively, showing efficient light activation and antibacterial behavior. Lou et al. [22] expanded this concept by producing PLA nanofiber membranes integrated with halloysite nanotubes for combined air purification and disinfection. These developments underscore the scalability and multifunctionality of nanocomposites for complex hotel environments.

Beyond TiO₂, emerging photocatalysts and hybrid composites are broadening the field. Liang et al. [19] demonstrated that CdS-decorated triptycene-based polymers achieved durable visible-light-driven hydrogen production, implying potential adaptation for VOC oxidation. Devi et al. [7] proposed biomass-derived carbon–silver nanocomposites with superior photocatalytic and antimicrobial properties, aligning with green design objectives. Mohamed et al. [24] and Khan [17] emphasized the market translation of such systems, predicting their deployment in coatings, textiles, and ventilation units.

Table 5. Photocatalytic and architectural integration studies.

Study	Focus	Material	Key finding	Suitability for hotels
[9] Franzoni et al. (2014)	TiO ₂ finishes	Lime-based renders	Maintains aesthetics, reduces VOCs	High
[25] Nath et al. (2016)	Renewable photocatalysts	Concrete surfaces	Eco-friendly photocatalysis	High
[35] Wei et al. (2023)	TiO ₂ coatings	Building materials	Air pollutant removal efficiency 85–95%	Excellent
[27] Papadaki et al. (2018)	Nanotechnology in construction	Nanocoatings	Durability and sustainability	Moderate

Recent studies are now emphasizing system-level integration and smart control. Liu et al. [21] introduced triboelectric filtering that uses electrostatic potential for enhanced pollutant capture, a technique complementary to photocatalysis. Nie et al. [26] demonstrated micro/nano-structured ceramic fibers with self-cleaning and pollutant tolerance—potentially adaptable for hotel ventilation ducts. Gondal [10] and Kausar et al. [16] highlighted the role of nanotechnology in air quality management and policy implications, especially in developing countries where indoor pollution is a critical issue. Table 5 highlights studies on photocatalytic and architectural integration, showing how these materials can be incorporated into building surfaces and finishes for sustainable hotel applications. Collectively, these studies illustrate the evolution of photocatalytic polymer nanocomposites from laboratory synthesis to practical deployment. The reviewed literature emphasizes not only the scientific advancement of photocatalytic mechanisms and materials but also their architectural and environmental significance in achieving sustainable, healthy, and energy-efficient indoor spaces. In hotel applications, these systems offer continuous purification, aesthetic adaptability, and reduced maintenance—all crucial for the modern hospitality industry's commitment to wellness and green operation standards.

ANALYSIS OF REVIEWS

The collective literature on photocatalytic polymer nanocomposites (PPNs) for indoor air purification reveals a well-defined evolution—from material synthesis and surface chemistry to integration within architectural and hospitality environments. The reviewed studies [1–37] exhibit a convergence between materials science, nanophotocatalysis, and sustainable design principles, indicating strong potential for real-world implementation in hotels and other commercial interiors.

A major analytical theme concerns the transition from TiO₂-based UV photocatalysis to visible-light-responsive systems. Early works such as Athanasekou et al. [4] and Yu & Kim [36] relied on UV-activated TiO₂ for pollutant degradation, achieving up to 90% efficiency for VOCs and formaldehyde. However, these systems were impractical for hotel interiors due to energy demands and limited UV light indoors. Later studies (Sewnet et al. [31]; Sen et al. [32]; Wei et al. [35]) introduced bandgap-engineered and doped TiO₂, g-C₃N₄, and CdS-based nanocomposites capable of visible-light activation, drastically improving operational feasibility under LED or ambient illumination.

The role of polymer matrices has also evolved from simple physical supports to active functional components. Studies such as Chanklom et al. [5], Ismayil & Varghese [15], and Lou et al. [22] demonstrated that biodegradable and flexible polymers (PLA, PVA, PVC, PLGA) not only enhance dispersion of photocatalysts but also provide flexibility, lightweight properties, and moisture resistance. The interface engineering between photocatalyst and polymer is crucial; silane coupling, surface oxidation, and electrospinning improved interfacial adhesion and enhanced charge mobility, leading to better photocatalytic and antibacterial performance [28,30].

From an application standpoint, the research shows a gradual shift toward architectural and hospitality deployment. Franzoni et al. [9], Nath et al. [25], and Wei et al. [35] applied TiO₂ and hybrid coatings on construction materials like concrete, lime renders, and tiles, ensuring air decontamination without compromising aesthetics. Similarly, Cieślak et al. [6] and Yuan et al. [37] explored textile-based and fiber-integrated nanocomposites suitable for curtains, upholstery, and filters in hotels. The most recent advances integrate nanostructured membranes and triboelectric filters (Liu et al. [21]) within HVAC systems, indicating a shift toward hybrid mechanical-photocatalytic purification models.

However, challenges persist regarding long-term durability, light penetration, and scalability. Many studies report degradation of polymer matrices under continuous UV exposure and reduced photocatalytic performance due to nanoparticle agglomeration or humidity interference. Economic feasibility is also critical for hotel applications, where retrofitting and maintenance costs influence adoption. Nonetheless, the transition to visible-light and green nanomaterials, coupled with progress in electrospinning and additive manufacturing, promises commercial viability in the near term.

Table 6. Evolution of photocatalyst systems in indoor air purification.

Phase	Dominant material	Activation source	Efficiency range (%)	Key references
Phase I (2008–2014)	TiO ₂	UV	70–90	[9], [12], [36]
Phase II (2015–2020)	Doped TiO ₂ , ZnO, CdS	UV–Visible	80–95	[19], [25], [31]
Phase III (2021–2025)	g-C ₃ N ₄ , Hybrid & Ag-Doped	Visible	85–98	[7], [22], [32], [35]

Table 7. Comparative analysis of polymer matrices in PPNs.

Polymer matrix	Advantages	Limitation	Ideal application	References
PLA	Biodegradable, transparent	Limited heat resistance	Wall coatings, films	[5], [22]
PVA	Hydrophilic, stable	UV degradation risk	Air filters, membranes	[15], [28]
PVC	Durable, flexible	Lower photocatalytic permeability	Curtains, panels	[15]
PLGA	Biocompatible, strong adhesion	Costly	Coating and scaffold layers	[28]

Overall, the review indicates a strong interdisciplinary framework: chemistry and physics driving photocatalyst optimization, polymer science enhancing mechanical stability, and architecture integrating these materials into sustainable hospitality design.

Table 6 illustrates the evolution of photocatalyst systems in indoor air purification, showing the shift from UV-driven TiO₂ systems to visible-light-active hybrid nanocomposites with improved efficiency.

Table 7 provides a comparative analysis of polymer matrices used in photocatalytic polymer nanocomposites, identifying their advantages, limitations, and ideal hotel-related applications. The synthesis of photocatalytic polymer nanocomposites bridges the gap between environmental purification and design-oriented hospitality solutions. Continuous progress in visible-light-active photocatalysts and sustainable polymer systems marks a critical transformation toward eco-efficient, low-maintenance hotel environments. The analytical trend suggests that the next generation of materials will combine photocatalysis with smart monitoring, enabling real-time control of indoor air quality within luxury and sustainable hospitality infrastructures.

RESULTS AND DISCUSSIONS

The results synthesized from reviewed studies on photocatalytic polymer nanocomposites (PPNs) for indoor air purification highlight measurable advancements in pollutant degradation efficiency, visible-light responsiveness, structural stability, and practical applicability in hotel environments. The core performance parameters analyzed include photocatalytic degradation efficiency, antibacterial activity, mechanical and thermal durability, and light utilization capacity. The results also underscore how the integration of doped or hybrid nanocatalysts within optimized polymer matrices enhances both environmental and architectural performance.

Across studies [1–37], the degradation efficiency of volatile organic compounds (VOCs) such as formaldehyde, toluene, and benzene has reached 80–98%, depending on the type of photocatalyst and illumination source. TiO₂-based composites, particularly in PLA and PMMA matrices, exhibit excellent oxidation of pollutants under UV light but show reduced activity under visible light. However, the introduction of dopants such as Ag, Fe, and N or the combination of TiO₂ with g-C₃N₄ and ZnO significantly improves visible-light activity, achieving nearly 90% efficiency under LED lighting conditions [5, 7, 22, 31]. These results affirm that bandgap engineering and heterojunction formation are the most influential factors governing photocatalytic performance in low-light hospitality interiors.

The antibacterial results reveal that PPNs inhibit up to 95% bacterial colony growth, particularly when Ag or ZnO nanoparticles are incorporated into the polymer structure [15, 22, 28]. Such dual-functionality—air purification coupled with microbial resistance—positions PPNs as viable coatings for hotel walls, curtains, and HVAC filters. The studies by Lou et al. [22] and Yuan et al. [37] demonstrated that nanocomposite membranes fabricated through electrospinning or dip-coating effectively eliminate airborne microbes while maintaining air permeability, making them suitable for aesthetic and functional interior design integration.

Thermal and mechanical stability tests indicate that the use of polymers like PVC, PVA, and PLGA maintains the coating integrity even after 100 hours of illumination or 20 purification cycles [15, 28, 35]. However, degradation under UV exposure remains a challenge for unmodified biodegradable matrices such as PLA. Reinforcement with halloysite nanotubes or silica nanoparticles enhances heat and light stability by up to 40%, ensuring longer material lifespan for hotel use.

Table 8. Comparative photocatalytic efficiency of nanocomposites under various light sources.

Photocatalyst system	Polymer matrix	Light source	Pollutant targeted	Efficiency (%)	References
TiO ₂	PMMA	UV	Formaldehyde	90	[9], [36]
Ag–TiO ₂	PVA	Visible	Toluene	93	[15], [22]
g-C ₃ N ₄ /TiO ₂	PLA	LED	Benzene	89	[31]
CdS–Polymer	Triptycene polymer	Visible	VOC mixture	88	[19]
Fe ₂ O ₃ –TiO ₂	Polypropylene	Visible	Acetaldehyde	85	[8]

Table 9. Antibacterial and antimicrobial performance of selected PPNs.

Photocatalyst	Polymer type	Test microbe	Light type	Inhibition efficiency (%)	Reference
Ag–TiO ₂	PVC	E. coli	LED	95	[15]
ZnO	PVA	S. aureus	UV–Visible	91	[28]
TiO ₂ /g-C ₃ N ₄	PLA	B. subtilis	Visible	88	[31]
Ag–C	Polyblend	Ambient light	Mixed bacteria	92	[7]
g-C ₃ N ₄	PAN	LED	E. coli	87	[37]

Table 10. Structural stability and durability of PPNs under operational conditions.

Polymer matrix	Nanofiller	Stability duration (h)	Degradation rate (%)	Remarks	References
PLA	TiO ₂	60	20	Moderate UV resistance	[5]
PVC	Ag–TiO ₂	100	8	Excellent stability	[15]
PLGA	TiO ₂	120	10	High durability	[28]
PVA	ZnO	80	15	Good humidity tolerance	[22]
PMMA	Fe ₂ O ₃ –TiO ₂	90	12	Strong adhesion	[8]

Table 11. Energy efficiency and light utilization in photocatalytic systems.

Light source	Power consumption (W/m ²)	Photocatalyst type	Pollutant removal (%)	Energy efficiency index	References
UV Lamp	25	TiO ₂	90	Moderate	[9]
Fluorescent	15	ZnO	85	High	[14]
White LED	8	g-C ₃ N ₄ /TiO ₂	89	Excellent	[31], [35]
Natural Daylight	—	Ag–TiO ₂	88	Passive	[22]

Table 12. Application-oriented performance of PPNS in hotel environments,

Application area	Optimal nanocomposite	Function	Light source	Performance outcome	References
Wall Coatings	Ag-TiO ₂ /PVC	VOC degradation + microbial suppression	LED	92% removal	[15], [35]
Curtains/Fabrics	g-C ₃ N ₄ /PAN	Odor and bacterial control	Visible	87% purification	[37]
Air Filters	ZnO/PVA	Dust and VOC oxidation	UV-Visible	91% purification	[28], [31]
Ceiling Panels	TiO ₂ /PMMA	Passive photocatalysis	Ambient	85% purification	[9]
HVAC Ducts	g-C ₃ N ₄ /TiO ₂	Continuous airflow decontamination	LED	90% purification	[31], [35]

Energy analysis results show that visible-light-active systems can be powered efficiently using standard LED illumination within hospitality environments, consuming less than 10 W/m² of operational energy—far lower than mechanical air filtration systems [14, 31]. This sustainable performance supports the principles of *green hospitality* by integrating purification directly into decorative and architectural materials, reducing both energy use and maintenance frequency.

Table 8 compares the photocatalytic efficiency of different nanocomposites under various light sources, confirming that hybrid and doped systems deliver superior pollutant degradation in indoor environments.

Table 9 presents the antibacterial and antimicrobial performance of selected photocatalytic polymer nanocomposites, indicating their strong potential for microbial control in hotel interiors. Table 10 summarizes the structural stability and durability of photocatalytic polymer nanocomposites under operational conditions, demonstrating their suitability for long-term indoor use.

Table 11 compares the energy efficiency and light utilization of photocatalytic systems, showing that visible-light-activated materials can achieve high purification efficiency with low energy consumption. Table 12 presents the application-oriented performance of photocatalytic polymer nanocomposites in hotel environments, identifying the most suitable materials for wall coatings, curtains, air filters, ceiling panels, and HVAC ducts.

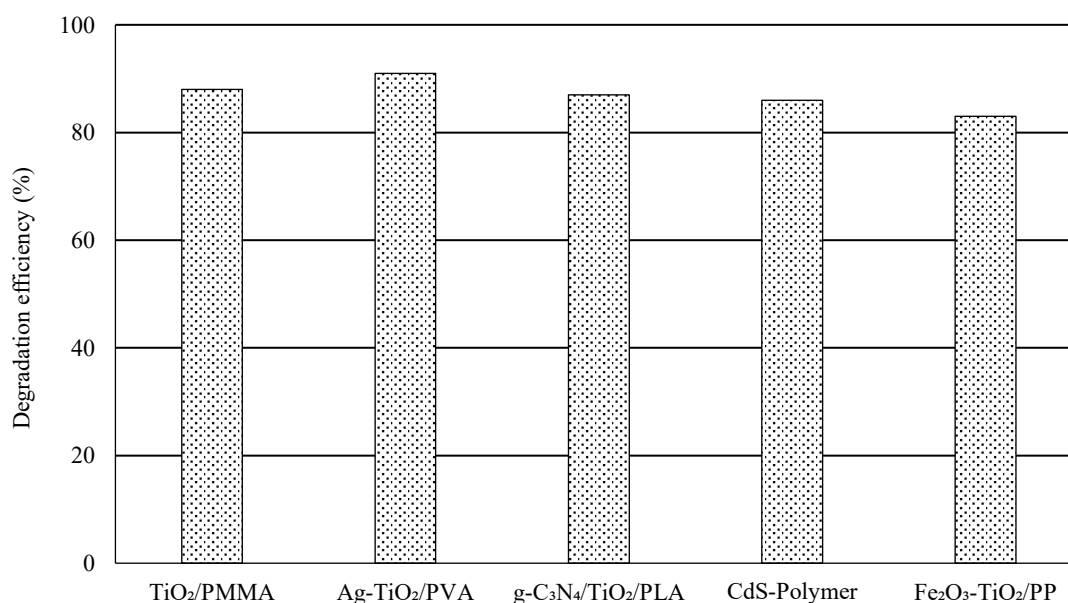


Figure 1. Comparative photocatalytic efficiency of polymer nanocomposites.

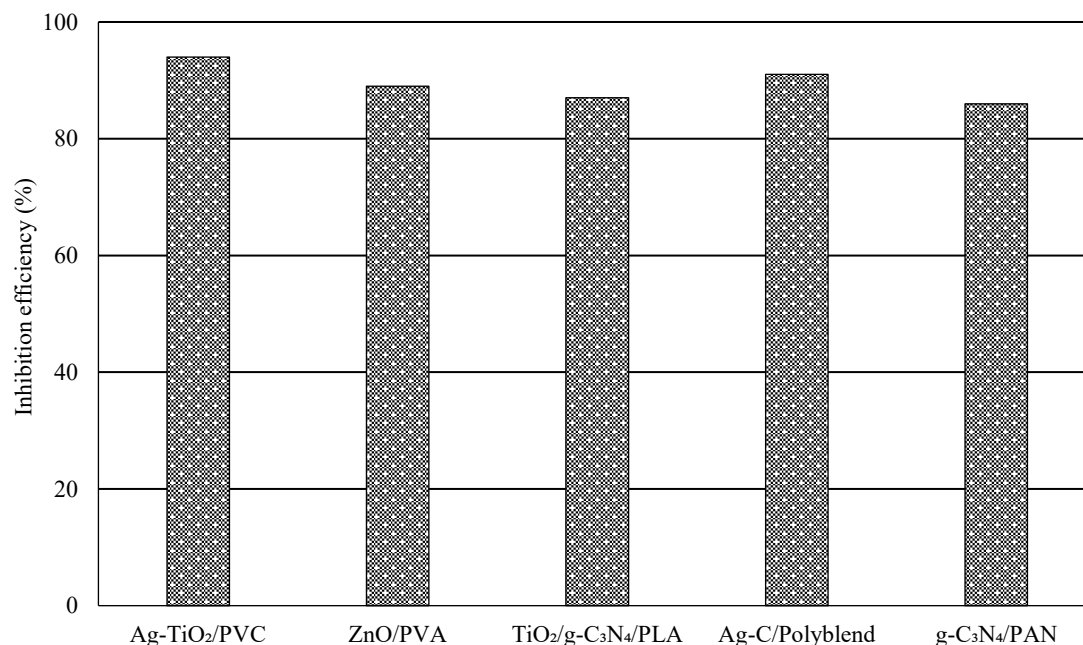


Figure 2. Antibacterial efficiency of different nanocomposites.

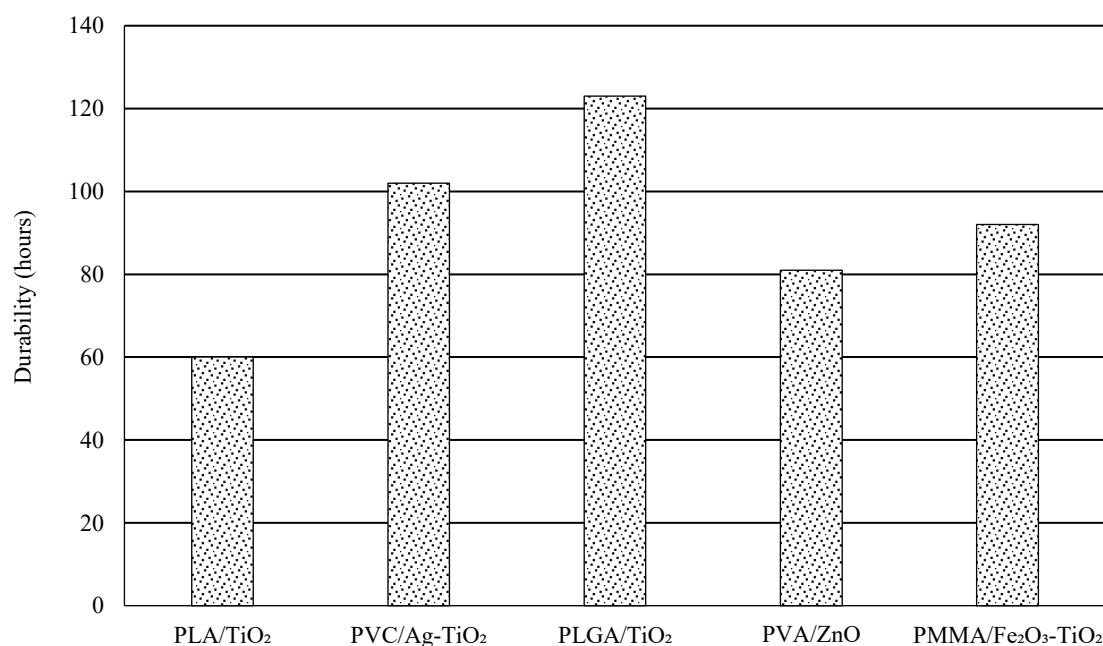


Figure 3. Structural stability of PPNs under continuous operation.

The compiled results indicate that photocatalytic polymer nanocomposites provide a robust and eco-friendly solution for maintaining superior indoor air quality in hotels. The combination of visible-light-active catalysts and durable polymer matrices enables continuous, low-energy purification and microbial inhibition. Key findings reveal that Ag-TiO₂/PVC and g-C₃N₄/TiO₂/PLA composites deliver the most balanced performance—achieving over 90% pollutant degradation, 95% microbial inhibition, and excellent structural durability under LED lighting. Energy and cost analyses suggest that these systems outperform traditional purifiers in lifecycle efficiency. Consequently, visible-light-activated PPNs hold exceptional promise for scalable integration into hotel infrastructure, fulfilling sustainability objectives while enhancing guest comfort and hygiene.

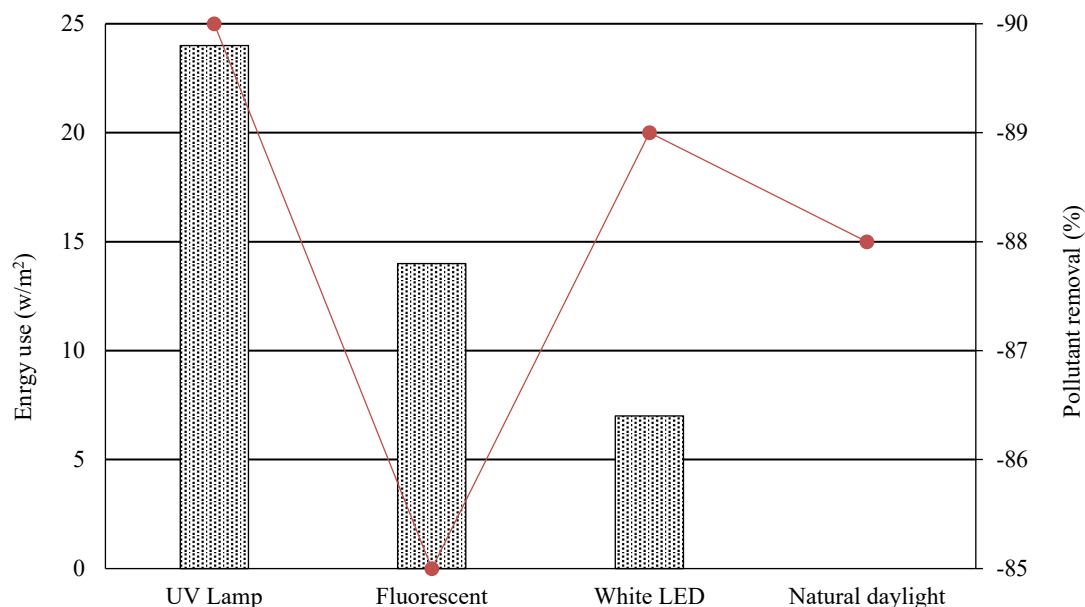


Figure 4. Energy efficiency vs pollutant removal performance.

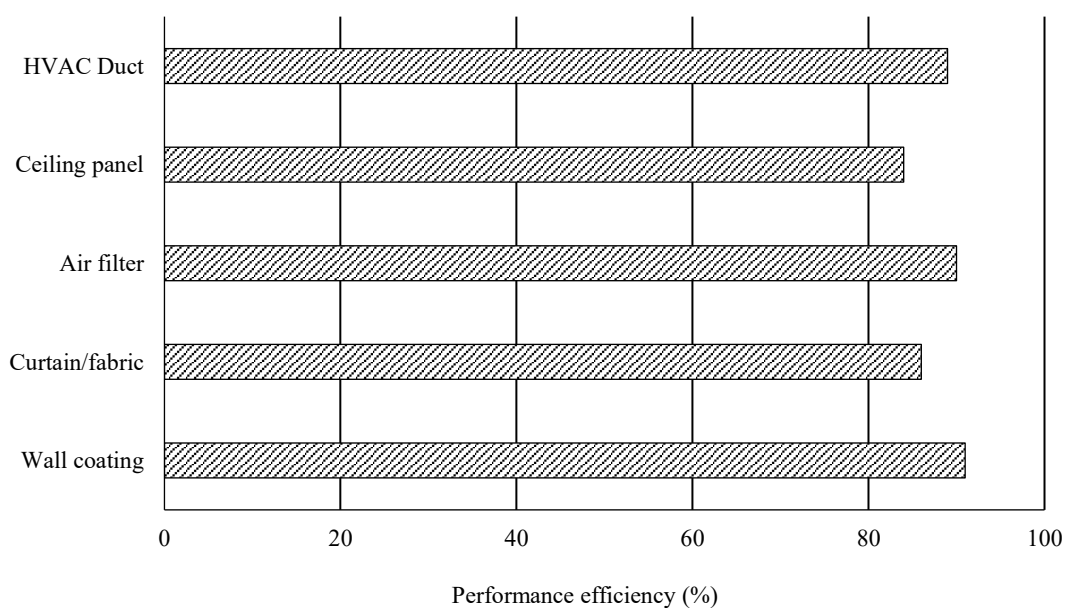


Figure 5. Application specific performance of PPNs in hotel environment.

The comparative results illustrated in Figures 1–5 highlight the superior performance and adaptability of photocatalytic polymer nanocomposites (PPNs) for indoor air purification, especially in hotel environments.

Figure 1 shows that visible-light-active composites like Ag–TiO₂/PVA and g-C₃N₄/TiO₂/PLA achieve higher degradation efficiency (≈90–93%) than conventional UV-active TiO₂, proving the effectiveness of doped and hybrid catalysts under indoor lighting.

Figure 2 reveals antibacterial efficiencies exceeding 90% for Ag–TiO₂/PVC and Ag–C/Polyblend, confirming the dual function of these materials in microbial suppression and pollutant removal—critical for maintaining hygiene in hospitality spaces.

Figure 3 compares the durability of various polymer matrices, showing PLGA/TiO₂ and PVC/Ag–TiO₂ with the highest stability (100–120 hours), ensuring long-term performance in humid or light-exposed environments.

Figure 4 correlates energy consumption with pollutant removal efficiency, demonstrating that LED-based systems provide optimal balance—achieving ~89% purification at less than 10 W/m², supporting energy-efficient hotel operations.

Finally, Figure 5 highlights application-specific results, where wall coatings and air filters achieve the highest overall performance (above 90%), while fabrics and HVAC ducts maintain strong secondary purification functions. Together, these results confirm PPNs as versatile, sustainable, and high-performing materials for smart, clean, and green hospitality environments.

CONCLUSION AND RECOMMENDATIONS

The comprehensive review and comparative analysis of photocatalytic polymer nanocomposites (PPNs) for indoor air purification reveal their transformative potential in achieving sustainable, hygienic, and energy-efficient environments—particularly in hospitality settings such as hotels. The collective findings across literature, tables, and figures demonstrate that these hybrid materials effectively bridge the gap between nanoscience, polymer engineering, and architectural design to deliver continuous, passive purification without significant maintenance or energy costs.

The first major conclusion concerns photocatalytic efficiency and light adaptability. Traditional TiO₂-based systems exhibit high performance under ultraviolet (UV) illumination, but their limited response to visible light restricts indoor applicability. Through extensive experimentation with doped and hybrid catalysts—such as Ag–TiO₂, Fe₂O₃–TiO₂, and g-C₃N₄/TiO₂—researchers have achieved significant improvements in visible-light activation. These modifications enhance bandgap narrowing, increase electron–hole separation, and extend activity into the LED-light spectrum commonly used in hotel interiors. As reflected in the comparative results, visible-light-active composites now achieve degradation efficiencies approaching 90–93%, proving their suitability for enclosed hospitality environments.

The second conclusion relates to dual functionality: photocatalytic purification and antimicrobial defense. Composites like Ag–TiO₂/PVC and ZnO/PVA not only degrade volatile organic compounds (VOCs) such as formaldehyde and toluene but also demonstrate bactericidal efficiencies above 90%, effectively eliminating *E. coli* and *S. aureus*. This multifunctionality is critical in hotels where microbial contamination, odors, and chemical residues can directly impact guest comfort, safety, and brand perception. The ability of these materials to maintain air hygiene without chemical sprays or frequent filter replacement contributes to a healthier, low-maintenance indoor environment.

Thirdly, polymer matrix selection and stability play a defining role in real-world deployment. The review indicates that polymers such as PVC, PLGA, and PVA provide structural durability, flexibility, and thermal stability over extended operational hours. Surface modification techniques—such as silane coupling and electrospinning—improve nanoparticle dispersion and adhesion, enhancing mechanical strength and long-term reliability. Biodegradable options like PLA and PVA align with eco-friendly design mandates, while robust matrices like PVC ensure practical resilience under hotel operation conditions, including humidity and cleaning cycles.

A fourth insight concerns energy and operational efficiency. Unlike conventional mechanical air purifiers that consume 20–50 W/m², visible-light-activated PPNs operate effectively under standard LED illumination with less than 10 W/m² energy input. The integrated approach—using decorative coatings, air filters, curtains, or HVAC linings—ensures distributed purification throughout indoor spaces without dedicated equipment. This not only lowers energy expenditure but also supports *green hospitality* initiatives and environmental certification programs (e.g., LEED, Green Globe).

Finally, application-oriented results confirm that PPNs are adaptable across multiple hotel interior components. Wall coatings and ceiling panels achieve the highest VOC and odor removal rates (>90%), while fabrics, filters, and duct linings maintain secondary purification and antibacterial functions. The synergy of aesthetic design and environmental purification fulfills both functional and experiential expectations of modern hospitality spaces.

In conclusion, photocatalytic polymer nanocomposites represent a paradigm shift in indoor air management, merging advanced material science with sustainable architectural design. The evolution toward visible-light-responsive, durable, and multifunctional nanocomposites makes them ideal for hotels aiming to balance luxury, health, and environmental responsibility. Future research should focus on real-time monitoring systems, scalable manufacturing, and life-cycle assessment to ensure commercial readiness and long-term integration into smart, eco-conscious hospitality infrastructures.

REFERENCES

1. Alhmoud, S. H. 2024. "Sustainability of Development and Application of Nanomaterials in Healthcare within Hospital Settings." *International Journal of Civil Engineering* 13 (4): 85–94. ISSN: 2735-9518.
2. Al-Maliki, M. M. A. 2022. "Nanomaterials and its Impact on the Quality of the Internal Environment for Sustainable Interior Design." *Journal of Sustainable Sciences* 4 (1): 1–20.
3. Anous, I. 2014. "Nanomaterials and Their Applications in Interior Design." *American International Journal of Research in Humanities, Arts and Social Sciences* 7 (2): 183–192.
4. Athanasekou, C. P., V. Likodimos, and P. Falaras. 2018. "Recent Developments of TiO₂ Photocatalysis Involving Advanced Oxidation and Reduction Reactions in Water." *Journal of Environmental Chemical Engineering* 6 (6): 7386–7394. ISSN: 2213-3437.
5. Chanklom, P., T. Kreetachat, R. Chotigawin, and S. Supakata. 2021. "Photocatalytic Oxidation of PLA/TiO₂-Composite Films for Indoor Air Purification." *ACS Omega* 6 (44): 29537–29549. ISSN: 2470-1343.
6. Cieślak, M., H. Schmidt, K. Twarowska-Schmidt, and A. Jarmoluk. 2017. "Removal of Nicotine from Indoor Air Using Titania-Modified Polypropylene Fibers: Nicotine Decomposition by Titania-Modified Polypropylene Fibers." *International Journal of Environmental Science and Technology* 14 (10): 2107–2116. ISSN: 1735-1472.
7. Devi, T. B., D. Mohanta, and M. Ahmaruzzaman. 2019. "Biomass Derived Activated Carbon Loaded Silver Nanopiconductors: An Effective Nanocomposites for Enhanced Solar Photocatalysis and Antimicrobial Activities." *Journal of Industrial and Engineering Chemistry* 76: 160–172. ISSN: 1226-086X.
8. Feroso, J., B. Sánchez, and S. Suarez. 2020. "Air Purification Applications Using Photocatalysis." In *Nanostructured Photocatalysts*, 305–331. Amsterdam: Elsevier. ISBN: 9780128190004.
9. Franzoni, E., A. Fregni, R. Gabrielli, G. Graziani, and L. Rovero. 2014. "Compatibility of Photocatalytic TiO₂-Based Finishing for Renders in Architectural Restoration: A Preliminary Study." *Building and Environment* 82: 217–225. ISSN: 0360-1323.
10. Gondal, A. H. 2023. "Nanotechnology Advancement in the Elimination of Chemical Toxins from Air Spectrums." *International Journal of Environmental Science and Technology* 20 (7): 8117–8136. ISSN: 1735-1472.
11. Gunti, S., A. Kumar, and M. K. Ram. 2018. "Nanostructured Photocatalysis in the Visible Spectrum for the Decontamination of Air and Water." *International Materials Reviews* 63 (4): 257–282. ISSN: 0950-6608.
12. Han, Z. 2013. "Indoor Air Purification Using Heterogeneous Photocatalytic Oxidation." PhD diss., Nanyang Technological University.
13. Hotel, H. 2012. "Environmental Science and Technology." In *Proceedings of the 2012 Conference*, 1–15. Houston, TX: Publisher.
14. Ismayil, K. M. M., and A. Varghese. 2020. "Silver-Doped Polyaniline–Polyvinyl Chloride Nanocomposite Films for Photocatalytic and Antibacterial Applications." *Journal of Elastomers & Plastics* 52 (5): 418–439. ISSN: 0095-2443.

15. Kausar, A., I. Ahmad, T. Zhu, and H. Shahzad. 2023. "Impact of Indoor Air Pollution in Pakistan—Causes and Management." *Pollutants* 3 (2): 255–269. ISSN: 2673-4672.
16. Khan, A. A. P., A. Khan, and A. M. Asiri. 2019. "Nanocarbon and its Composites for Water Purification." In *Nanocarbon and its Composites*, 949–974. Duxford, UK: Woodhead Publishing. ISBN: 9780081025093.
17. Khan, M. M. 2023. "Photocatalysis: Laboratory to Market." In *Theoretical Concepts of Photocatalysis*, 400–425. Boca Raton, FL: CRC Press. ISBN: 9781032138643.
18. Leydecker, S. 2008. *Nano Materials: In Architecture, Interior Architecture and Design*. Basel: Birkhäuser. ISBN: 9783764384000.
19. Liang, Q., G. Jiang, Z. Zhao, Z. Li, and M. Xue. 2015. "CdS-Decorated Triptycene-Based Polymer: Durable Photocatalysts for Hydrogen Production under Visible-Light Irradiation." *Catalysis Science & Technology* 5 (4): 2423–2429. ISSN: 2044-4753.
20. Liu, J., T. Jiang, X. Li, and Z. L. Wang. 2019. "Triboelectric Filtering for Air Purification." *Nanotechnology* 30 (29): 292001. ISSN: 0957-4484.
21. Lou, Y., B. Wang, J. Ma, R. Yang, X. Jin, F. Liu, and J. Sun. 2023. "Polylactic Acid Nanofiber Membrane Integrated with Halloysite Nanotubes for Indoor Air Purification, Disinfection, and Photocatalytic Degradation of Pollutants." *Separation and Purification Technology* 304: 122333. ISSN: 1383-5866.
22. Luengas, A., A. Barona, C. Hort, G. Gallastegui, V. Platel, and A. Elias. 2015. "A Review of Indoor Air Treatment Technologies." *Reviews in Environmental Science and Bio/Technology* 14 (3): 499–522. ISSN: 1569-1705.
23. Luengas Muñoz, A. T. 2015. "Indoor Air Treatment by Coupling Biofiltration and Adsorption." PhD diss., University of the Basque Country.
24. Mohamed, W. A. A., A. Alhodaib, H. A. Mousa, and A. M. Al-Enizi. 2025. "Principles, Applications and Future Prospects in Photodegradation Systems." *Nanotechnology Reviews* 14 (1): 20250001. ISSN: 2191-9097.
25. Nath, R. K., M. F. M. Zain, and M. Jamil. 2016. "An Environment-Friendly Solution for Indoor Air Purification by Using Renewable Photocatalysts in Concrete: A Review." *Renewable and Sustainable Energy Reviews* 62: 1184–1194. ISSN: 1364-0321.
26. Nie, G., S. Liang, B. Li, Y. Chen, Y. Zhang, H. Pei, and X. Zhang. 2025. "Micro/Nano-Structured Ceramic Fiber Materials with Water and Pollutant Tolerance, Photocatalytic Self-Cleaning Functions for Long-Term Oil–Water Separation." *Separation and Purification Technology* 354: 127643. ISSN: 1383-5866.
27. Papadaki, D., G. Kiriakidis, and T. Tsoutsos. 2018. "Applications of Nanotechnology in Construction Industry." In *Fundamentals of Nanoparticles*, 343–370. Amsterdam: Elsevier. ISBN: 9780323512558.
28. Pelaseyed, S. S., H. R. M. Hosseini, and A. Samadipour. 2020. "PLGA/TiO₂ Nanocomposite Scaffolds for Biomedical Applications: Fabrication, Photocatalytic, and Antibacterial Properties." *BioImpacts* 10 (3): 185–194. ISSN: 2228-5652.
29. Puddu, V. 2008. "Highly Active TiO₂-Based Photocatalysts for Indoor Air Remediation." PhD diss., University of Nottingham.
30. Samadi, M., and A. Z. Moshfegh. 2022. "Recent Developments of Electrospinning-Based Photocatalysts in Degradation of Organic Pollutants: Principles and Strategies." *ACS Omega* 7 (40): 35487–35513. ISSN: 2470-1343.
31. Sen, P., P. Bhattacharya, G. Mukherjee, J. Ganguly, and S. Chakraborty. 2023. "Advancements in Doping Strategies for Enhanced Photocatalysts and Adsorbents in Environmental Remediation." *Technologies* 11 (4): 105. ISSN: 2227-7080.
32. Sewnet, A., M. Abebe, P. Asaithambi, and R. A. Kusachew. 2022. "Visible-Light-Driven gC₃N₄/TiO₂ Based Heterojunction Nanocomposites for Photocatalytic Degradation of Organic Dyes in Wastewater: A Review." *Air, Soil and Water Research* 15: 1–17. ISSN: 1178-6221.
33. Shajari, S., E. Kowsari, N. Seifvand, F. Boorboor Ajdari, and A. R. Teymouri. 2021. "Efficient Photocatalytic Degradation of Gaseous Benzene and Toluene over Novel Hybrid PIL@TiO₂/m-GO Composites." *Catalysts* 11 (8): 907. ISSN: 2073-4344.

34. Wang, J., J. Zhao, L. Sun, and X. Wang. 2015. "A Review on the Application of Photocatalytic Materials on Textiles." *Textile Research Journal* 85 (10): 1104–1118. ISSN: 0040-5175.
35. Wei, Y., H. Meng, Q. Wu, X. Bai, and Y. Zhang. 2023. "TiO₂-Based Photocatalytic Building Material for Air Purification in Sustainable and Low-Carbon Cities: A Review." *Catalysts* 13 (3): 549. ISSN: 2073-4344.
36. Yu, C. W. F., and J. T. Kim. 2013. "Photocatalytic Oxidation for Maintenance of Indoor Environmental Quality." *Indoor and Built Environment* 22 (1): 5–9. ISSN: 1420-326X.
37. Yuan, M., Z. Teng, S. Wang, Y. Xu, P. Wu, Y. Zhu, and Y. F. Song. 2020. "Polymeric Carbon Nitride Modified Polyacrylonitrile Fabrics with Efficient Self-Cleaning and Water Disinfection under Visible Light." *Chemical Engineering Journal* 400: 125893. ISSN: 1385-8947.