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Post-COVID Building Renovations and Indoor Air Quality Risks: Volatile Organic Compound and Particulate Matter Exposure in Nigerian Buildings

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Abstract: The post-COVID period has been marked by widespread building renovations as residential, commercial, and institutional spaces were adapted for new patterns of occupancy, ventilation, and hygiene. While these renovations aimed to improve comfort, infection control, and functionality, they have also introduced unintended indoor air quality risks, particularly in rapidly urbanising contexts such as Nigeria. From a broad perspective, renovation-driven indoor pollution reflects the growing intersection between construction practices, material chemistry, and public health in low- and middle-income countries. This study examines indoor air quality risks associated with post-COVID building renovations in Nigerian buildings, with a specific focus on exposure to volatile organic compounds (VOCs) and particulate matter (PM). Renovation activities including painting, varnishing, flooring replacement, installation of synthetic furnishings, and increased use of sealants and adhesives are known sources of VOC emissions such as formaldehyde, benzene, toluene, and xylene, alongside fine particulates generated from sanding, cutting, and demolition. These pollutants are of particular concern in buildings with limited mechanical ventilation and high occupant density. Narrowing the analysis, the paper explores exposure pathways relevant to Nigerian climatic, architectural, and socioeconomic conditions. Prolonged indoor occupancy following COVID-19, reliance on natural ventilation, and delayed off-gassing periods following renovations collectively elevate inhalation risks. Vulnerable populations including children, older adults, and individuals with asthma or cardiovascular disease face heightened susceptibility to these pollutants. The study synthesizes existing measurement studies, building material characteristics, and post-occupancy behavioural patterns to illustrate how short-term renovation decisions can produce long-term indoor exposure burdens. The findings highlight the need for improved building guidelines, material regulation, and post-renovation ventilation strategies. Integrating indoor air quality considerations into post-pandemic building recovery policies is essential to avoid substituting infectious disease risk with chronic environmental health hazards.
Keywords: Indoor air quality; post-COVID renovations; volatile organic compounds; particulate matter; building materials; Nigeria

1. INTRODUCTION

1.1 Post-COVID Building Transformation and Indoor Environmental Health

The period following the acute phase of the COVID-19 pandemic was characterised by a rapid and widespread transformation of the built environment. Across residential, commercial, and institutional settings, building renovations accelerated as occupants and organisations adapted spaces to new patterns of work, mobility, and daily life [1]. Homes were retrofitted to accommodate prolonged occupancy, offices were reconfigured to limit shared air circulation, and public facilities adopted new surface materials and spatial layouts intended to support hygiene and comfort [2]. These renovation trends were global in scope, extending beyond high-income regions into rapidly urbanising cities where recovery strategies intersected with existing infrastructure constraints.

A defining feature of this transformation was the shift toward more enclosed, refurbished, and intensively used indoor spaces [3]. Measures intended to improve thermal efficiency, security, and environmental control often resulted in reduced natural ventilation and tighter building envelopes [2]. In parallel, increased reliance on synthetic construction materials, composite furnishings, and chemical finishes altered the indoor environmental profile of many buildings. Spaces previously designed for intermittent use were repurposed for sustained daily occupancy, particularly as home-based work and indoor social activities expanded.

This evolving built environment landscape created exposure contexts that were rarely anticipated during renovation planning [4]. Materials selected for durability or ease of maintenance frequently carried emission characteristics with implications for indoor air quality [5]. At the same time, extended indoor residence increased both the duration and intensity of occupant exposure to airborne contaminants. The convergence of renovation-driven material changes and altered occupancy patterns represents a critical yet underexplored dimension of post-pandemic recovery [6]. Understanding how these structural adaptations intersect with indoor environmental health is essential for linking pandemic response measures to emerging indoor air quality concerns within broader urban and public health frameworks [7] globally today.

1.2 Indoor Air Quality as an Overlooked Post-Pandemic Risk

Despite the centrality of indoor environments to everyday life, indoor air quality has historically received less policy attention than outdoor air pollution or communicable disease control [8]. During pandemic response periods, ventilation discourse was largely framed through an infection-prevention lens, emphasising airflow as a mechanism for reducing viral transmission rather than as a determinant of overall indoor environmental quality [2]. As a result, chemical and particulate exposures associated with building modifications received comparatively limited scrutiny within public health planning.

Volatile organic compounds and particulate matter occupy a critical position within this overlooked risk landscape. VOCs are emitted from a wide array of renovation-related materials, including paints, sealants, adhesives, flooring products, and treated furnishings commonly introduced during refurbishment activities [4]. Fine and ultrafine particulate matter is generated through construction processes such as sanding, cutting, demolition, and the subsequent resuspension of settled dust. Unlike infectious agents, these pollutants often produce cumulative and subclinical health effects that may not be immediately perceptible.

Renewed attention to VOCs and particulate matter is warranted as indoor occupancy patterns intensify and exposure durations lengthen [9]. Evidence from diverse urban contexts indicates that indoor pollutant concentrations frequently exceed outdoor levels, particularly in enclosed spaces with limited ventilation and high occupant density [7]. Associated health outcomes range from sensory irritation and respiratory symptoms to longer-term cardiopulmonary and neurological effects, with heightened vulnerability among children, older adults, and individuals with pre-existing conditions.

Reframing indoor air quality as a post-pandemic risk requires moving beyond infection-centric paradigms toward a more integrated understanding of indoor environmental health. This perspective recognises renovation-driven emissions as structural components of exposure rather than incidental by-products of recovery activities [8]. Such reframing provides a logical transition toward examining renovation-related indoor pollution as a persistent and policy-relevant public health challenge [5].

2. CONCEPTUAL FRAMEWORK: RENOVATION ACTIVITIES AND INDOOR POLLUTANT PATHWAYS

2.1 Building Renovation as a Source of Indoor Chemical and Particulate Emissions

Building renovation activities constitute a significant yet frequently underestimated source of indoor chemical and particulate emissions. Processes such as repainting, surface refinishing, flooring replacement, and interior reconfiguration introduce a wide array of materials whose emission characteristics directly shape indoor air composition [6]. Paints, sealants, and adhesives commonly used during refurbishment release volatile organic compounds throughout application and curing phases, with emission profiles influenced by formulation, application thickness, and ambient temperature [9]. Composite materials, including laminated wood products and synthetic panels, may emit additional compounds over extended periods following installation.

Beyond chemical emissions, renovation activities generate substantial quantities of particulate matter. Mechanical actions such as sanding, cutting, drilling, and demolition release fine and coarse particles that readily become airborne in enclosed environments [11]. These particles often include mineral dust, fibres, and residues from treated surfaces, many of which persist indoors long after renovation activities have ceased. In buildings where cleaning is delayed or incomplete, resuspension of settled dust through routine movement further prolongs exposure [14].

The scale of emissions is shaped by renovation intensity and building characteristics. Small-scale domestic renovations may produce lower absolute emissions but occur in compact spaces with limited ventilation, increasing concentration levels [7]. Larger commercial refurbishments introduce higher material volumes and longer activity durations, frequently overlapping with partial occupancy. In both contexts, emission sources are often temporally concentrated yet spatially diffuse, allowing pollutants to migrate across rooms and floors.

Importantly, renovation emissions are rarely isolated events. In many urban settings, incremental upgrades occur repeatedly over short intervals, creating cumulative indoor pollution burdens [10]. The episodic nature of renovation activities complicates exposure assessment, as peak concentrations may coincide with periods of extended indoor occupancy. Recognising renovation as a multifaceted emission source provides a necessary transition from activity-based descriptions toward a pollutant-centred understanding of indoor air quality dynamics [15].

2.2 VOC and Particulate Matter Dynamics in Enclosed Indoor Spaces

Once released, volatile organic compounds and particulate matter follow distinct yet interconnected pathways within enclosed indoor environments. VOC emissions typically exhibit an initial high-release phase immediately after material application, followed by gradual decay as compounds diffuse from surfaces and bulk materials [8]. The persistence of this process varies widely depending on chemical volatility, material porosity, and ambient conditions. In some cases, low-volatility compounds may off-gas for months, contributing to sustained background concentrations [12].

Particulate matter behaves differently, with indoor dynamics governed by particle size, air movement, and surface interactions. Fine particles remain suspended for extended periods, particularly in low-ventilation environments, while larger particles settle more rapidly onto indoor surfaces [6]. However, settled particles are not permanently removed; routine activities such as walking, cleaning, or opening doors can resuspend particulates, effectively recycling pollutants within indoor air [13].

Ventilation plays a central role in mediating both VOC and particulate concentrations. Adequate air exchange can dilute indoor pollutants and accelerate removal, whereas restricted ventilation promotes accumulation and prolongs exposure [9]. In naturally ventilated buildings, airflow patterns are often inconsistent and climate-dependent, leading to uneven pollutant distribution across spaces. Mechanical ventilation systems, where present, may be insufficiently designed to address chemical emissions, particularly when filters are optimised primarily for thermal comfort rather than pollutant removal.

Surface adsorption further complicates indoor pollutant dynamics. VOCs can sorb onto walls, furnishings, and textiles, acting as secondary emission sources long after primary activities conclude [11]. Similarly, particulate matter deposited on surfaces may interact with absorbed chemicals, altering toxicity profiles. These processes underscore the importance of viewing indoor air quality as a dynamic system shaped by continuous exchanges between air, surfaces, and occupants [14]. Establishing this conceptual framework lays the groundwork for examining downstream health implications arising from sustained indoor exposure [15].

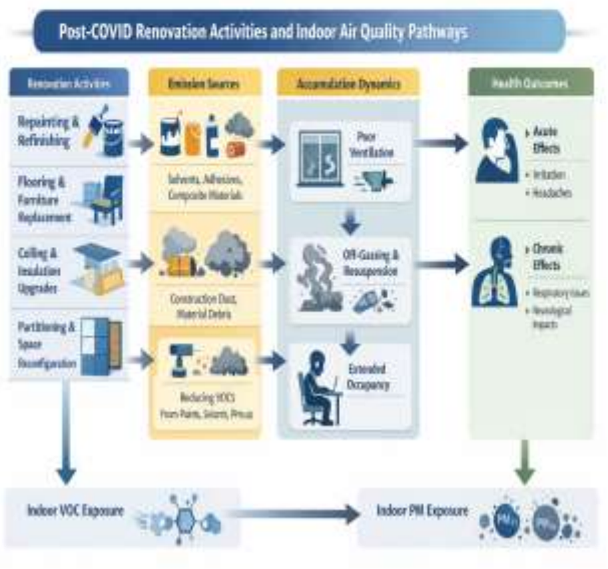

Figure 1: *Conceptual model linking post-COVID renovation activities to indoor VOC and particulate matter exposure pathways*

3. HEALTH IMPLICATIONS OF RENOVATION-RELATED INDOOR AIR POLLUTION

3.1 Volatile Organic Compounds and Human Health Outcomes

Volatile organic compounds emitted during building renovation activities have been consistently associated with a range of adverse human health outcomes. Acute exposure to elevated VOC concentrations commonly produces sensory and neurological symptoms, including eye and throat irritation, headaches, dizziness, and nausea [13]. These effects are often reported shortly after renovation activities, particularly in enclosed spaces where ventilation is limited and off-gassing rates are highest. Although such symptoms are frequently transient, they serve as early indicators of indoor chemical exposure [16].

Beyond immediate discomfort, prolonged or repeated exposure to VOCs raises concerns regarding chronic health effects. Certain compounds commonly found in renovation materials have been linked to respiratory inflammation, reduced lung function, and exacerbation of asthma-like symptoms [18]. Neurological outcomes, including impaired cognitive performance, fatigue, and mood disturbances, have also been observed in environments with sustained VOC presence [14]. These effects may arise even at concentrations below occupational exposure limits, highlighting the vulnerability of residential settings where exposure occurs continuously rather than intermittently.

The health impact of VOC exposure is further shaped by chemical mixtures rather than individual compounds in isolation. Indoor environments typically contain complex combinations of solvents, aldehydes, and semi-volatile compounds, which may interact synergistically [20]. Such mixtures complicate risk assessment and obscure causal attribution, particularly when exposure occurs alongside other indoor pollutants. Moreover, renovation-related VOC emissions often coincide with behavioural changes that increase exposure duration, such as prolonged indoor occupancy.

Importantly, VOC-related health effects are not uniformly distributed across populations. Individual susceptibility varies based on age, pre-existing conditions, and cumulative exposure history [22]. Recognising these differential outcomes provides a necessary foundation for understanding how renovation-driven indoor pollution contributes to broader patterns of environmental health risk.

3.2 Particulate Matter Exposure in Indoor Environments

Particulate matter generated during renovation activities represents a parallel and equally significant indoor health hazard. Fine particles with aerodynamic diameters below 2.5 micrometres ($PM_{2.5}$) and coarse particles up to 10 micrometres (PM_{10}) readily penetrate indoor spaces during construction and refurbishment processes [15]. Once indoors, these particles may deposit on surfaces or remain suspended, depending on size, air movement, and ventilation conditions.

Indoor deposition patterns influence exposure pathways. $PM_{2.5}$ particles are particularly persistent, remaining airborne for extended periods and penetrating deep into the respiratory tract upon inhalation [17]. PM_{10} particles, while settling more rapidly, contribute to upper airway irritation and are easily resuspended through everyday activities. Renovation dust often contains heterogeneous material components, including mineral fragments, fibres, and residues from treated surfaces, which may amplify toxicity [21].

Cardiopulmonary implications of particulate matter exposure have been extensively documented in environmental health literature. Inhalation of fine particles has been associated with increased respiratory symptoms, reduced pulmonary function, and heightened cardiovascular stress [13]. In indoor settings, these effects may be intensified by prolonged exposure durations and limited dilution opportunities. Evidence suggests that indoor PM exposure can rival or exceed outdoor exposure levels, particularly in buildings undergoing active or recent renovation [19].

The health burden associated with indoor particulate matter is further compounded by its interaction with gaseous pollutants. Particles may act as carriers for adsorbed organic compounds, facilitating deeper lung penetration of toxic substances [16]. This interaction underscores the need to consider particulate matter not merely as a physical irritant but as a complex vector within indoor pollution systems. Such dynamics reinforce the importance of integrating particulate exposure into broader assessments of renovation-related health risks [22].

3.3 Vulnerable Populations in Renovated Indoor Settings

While renovation-related indoor air pollution affects all occupants, certain population groups face disproportionately higher risks. Children are particularly vulnerable due to higher breathing rates relative to body size and ongoing physiological development [14]. Exposure during early life stages has been linked to long-term respiratory and neurodevelopmental consequences, making indoor pollutant control a critical concern in residential settings.

Older adults also exhibit increased susceptibility to indoor air pollutants. Age-related declines in respiratory and cardiovascular function reduce the body's ability to compensate for pollutant exposure [18]. Chronic conditions such as hypertension, chronic obstructive pulmonary disease, and heart disease further heighten sensitivity to both VOCs and particulate matter. For individuals with pre-existing illness, renovation-related exposures may trigger symptom exacerbation or accelerate disease progression [20].

Occupants with chronic respiratory or neurological conditions represent another high-risk group. Asthma, allergic disorders, and chemical sensitivities can be aggravated by even modest increases in indoor pollutant concentrations [15]. In renovated spaces where emissions persist over extended periods, these individuals may experience sustained health impacts that are not immediately recognised.

Socioeconomic factors also influence vulnerability. Populations with limited housing choice may remain in recently renovated environments without adequate ventilation or recovery periods [21]. Limited access to information about indoor air quality risks further compounds exposure. Recognising these vulnerable groups provides a critical transition toward examining how contextual factors shape exposure patterns in specific urban settings, preparing the groundwork for Nigeria-focused analysis in subsequent sections [22].

4. NIGERIAN BUILDING CONTEXT AND POST-COVID RENOVATION PRACTICES

4.1 Urbanisation, Housing Typologies, and Ventilation Practices in Nigeria

Rapid urbanisation has profoundly shaped housing conditions and indoor environmental quality in Nigerian cities. Population growth, rural–urban migration, and constrained urban planning capacity have produced dense residential environments characterised by compact housing units and limited open space [19]. In many urban areas, buildings are constructed to maximise occupancy rather than environmental performance, resulting in layouts that restrict airflow and natural light penetration. These conditions form a critical backdrop for understanding indoor air quality risks.

Natural ventilation remains the dominant strategy for indoor climate control across most Nigerian housing typologies. Windows, doors, and informal openings are relied upon to regulate temperature and air exchange, particularly in the absence of widespread mechanical ventilation systems [22]. While natural ventilation can dilute indoor pollutants under favourable conditions, its effectiveness is highly variable and dependent on building orientation, external airflow, and surrounding land use. In high-density neighbourhoods, closely spaced buildings and perimeter fencing often obstruct cross-ventilation, reducing pollutant removal efficiency [25].

Informal construction practices further complicate ventilation dynamics. Many residential structures are built incrementally, without formal architectural design or regulatory oversight [20]. Modifications such as window sealing, space partitioning, and ad hoc extensions are common, frequently undertaken to improve security or privacy. These alterations may unintentionally reduce air exchange rates and increase pollutant accumulation. Building materials selected for affordability rather than emission performance may introduce additional chemical sources indoors.

The interaction between dense housing, reliance on natural ventilation, and informal construction creates indoor environments that are highly sensitive to pollution sources [27]. These structural characteristics establish baseline vulnerabilities that amplify the impact of renovation-related emissions, providing essential context for analysing post-pandemic building modifications within Nigerian cities [23].

4.2 Post-COVID Renovation Trends in Residential and Commercial Buildings

In the period following widespread pandemic disruptions, building renovation activity increased across both residential and commercial sectors in Nigeria. Renovations were frequently motivated by changing functional requirements, including the need for adaptable workspaces, improved hygiene, and enhanced comfort [21]. Residential buildings underwent aesthetic upgrades such as repainting, ceiling replacement, and flooring changes, while commercial properties pursued spatial reconfiguration to accommodate altered occupancy patterns.

Material substitution emerged as a defining feature of these renovations. Synthetic paints, composite wood products, plastic-based flooring, and chemical sealants were widely adopted due to their availability and perceived durability [26]. While these materials offered short-term functional benefits, they also introduced new sources of volatile organic compounds and fine particulate matter. In many cases, renovations were completed rapidly, with minimal consideration of emission characteristics or post-installation ventilation requirements [19].

Social drivers played a significant role in shaping renovation choices. Buildings were refurbished to signal recovery, resilience, and economic activity following periods of disruption [24]. In commercial settings, visual modernisation became a strategy for attracting tenants and customers, while residential upgrades were linked to increased time spent indoors. These socially driven decisions often prioritised appearance and functionality over environmental performance.

Renovation activities frequently occurred alongside continued occupancy, particularly in residential buildings where temporary relocation was not feasible [27]. As a result, occupants were exposed to emissions during and immediately after refurbishment, when pollutant concentrations are typically highest. The convergence of material substitution, rapid renovation timelines, and sustained indoor presence transformed social recovery practices into environmental exposure pathways. This linkage underscores how post-pandemic renovation trends, though socially and economically motivated, produced unintended indoor air quality outcomes that warrant systematic examination [22].

4.3 Regulatory and Institutional Gaps in Indoor Air Quality Management

Regulatory oversight of indoor air quality in Nigeria remains limited, particularly in relation to residential and small-scale commercial buildings. While environmental regulations address outdoor air pollution and industrial emissions, enforceable standards specific to indoor environments are largely absent [25]. Building codes primarily focus on structural safety and land use compliance, offering minimal guidance on ventilation performance or material emissions.

Institutional responsibilities for indoor air quality management are fragmented across multiple agencies. Environmental authorities, urban planning departments, and public health institutions operate with overlapping mandates but limited coordination [20]. This fragmentation creates gaps in accountability, particularly for renovation activities conducted outside formal approval processes. Informal refurbishments, which constitute a substantial proportion of building modifications, often proceed without inspection or environmental assessment [23].

The absence of standardised indoor air quality benchmarks further constrains risk management. Without clear exposure limits or monitoring requirements, indoor pollution remains largely invisible within regulatory frameworks [21]. Occupants and building owners may be unaware of potential health risks associated with renovation materials, while policymakers lack empirical data to guide intervention. Enforcement mechanisms for existing building regulations are also uneven, particularly in high-density urban areas.

These regulatory and institutional gaps have significant implications for public health. Renovation-related emissions occur within a governance context that provides limited protection against indoor environmental hazards [26]. Addressing indoor air quality risks therefore requires not only technical solutions but also institutional reform. Recognising these systemic limitations provides a necessary transition toward evaluating exposure pathways and health impacts within Nigerian urban settings [27].

Table 1: Common Post-COVID Renovation Activities and Associated Volatile Organic Compound and Particulate Matter Emissions

Renovation Activity	Typical Materials or Processes Involved	Primary VOC Emissions	Primary Particulate Matter Emissions	Indoor Exposure Characteristics
Interior repainting and wall finishing	Emulsion paints, oil-based paints, primers, solvents	Formaldehyde, toluene, xylene, ethylbenzene	Minimal direct PM; secondary particle formation possible	High short-term VOC peaks with gradual decay; prolonged off-gassing in enclosed spaces
Flooring replacement and surface refinishing	Vinyl flooring, laminate boards, adhesives, sealants	Styrene, benzene derivatives, aldehydes	Fine dust from removal and sanding ($PM_{2.5}$, PM_{10})	Combined chemical exposure and dust resuspension during installation
Ceiling replacement and insulation upgrades	Synthetic panels, foam insulation, bonding agents	Isocyanates, semi-volatile organic compounds	Fibrous particulates and fine construction dust	Persistent particulate settling with intermittent resuspension
Furniture replacement and built-in	Composite wood products, varnishes	Formaldehyde, acetone, solvent	Low direct PM; surface-bound	Long-term low-level VOC emissions

Renovation Activity	Typical Materials or Processes Involved	Primary VOC Emissions	Primary Particulate Matter Emissions	Indoor Exposure Characteristics
installations	, lacquers	mixtures	particle release	from composite materials
Sanding, cutting, and minor demolition works	Plaster, cement, wood, treated surfaces	Indirect VOC release from disturbed coatings	High PM_{10} and $PM_{2.5}$ generation	Short-term intense particle exposure with delayed clearance
Sealant and adhesive application	Silicone sealants, epoxy resins, glues	Aromatic hydrocarbons, ketones	Negligible PM	Localised high VOC concentrations with slow decay

5. EXPOSURE PATHWAYS AND INDOOR ACCUMULATION MECHANISMS

5.1 Emission Persistence and Off-Gassing in Renovated Spaces

Renovation-related emissions are characterised not only by their intensity during active refurbishment but also by their persistence long after visible work has concluded. Many materials introduced during renovation exhibit off-gassing behaviours that extend beyond initial installation, creating prolonged indoor exposure conditions [23]. Short-term emissions typically occur immediately following application, when solvents and volatile compounds are released at elevated rates. These peak concentrations often coincide with continued occupancy, particularly in residential settings where relocation is impractical.

Long-term emissions arise as compounds slowly diffuse from material matrices, including paints, adhesives, composite boards, and treated furnishings [27]. This gradual release process may persist for weeks or months, contributing to sustained background concentrations that are less perceptible yet potentially more harmful due to continuous exposure. Material aging further modifies emission profiles, as chemical degradation, surface abrasion, and temperature fluctuations influence release rates over time [30].

Cumulative effects are especially relevant in environments undergoing repeated or staged renovations. Incremental upgrades, such as repainting or flooring replacement, may occur at intervals short enough to prevent complete decay of earlier emissions [25]. Over time, these overlapping sources generate layered exposure scenarios that challenge traditional assumptions of transient indoor pollution. The accumulation of multiple low-level emissions can produce pollutant mixtures with additive or synergistic health effects.

Environmental conditions within the building also shape emission persistence. Elevated indoor temperatures accelerate chemical volatilisation, while humidity influences material permeability and surface interactions [32]. In spaces with limited ventilation, decay processes are further slowed, allowing pollutants to remain airborne or adsorbed onto indoor surfaces. Understanding emission persistence and off-gassing dynamics is therefore critical for linking renovation activities to sustained indoor air quality degradation [28].

5.2 Indoor Occupancy Patterns in the Post-COVID Period

Changes in indoor occupancy patterns have played a central role in shaping exposure intensity to renovation-related pollutants. Shifts toward remote work and home-based activities significantly increased the amount of time individuals spend indoors [24]. Spaces once used intermittently became primary environments for work, education, and social interaction, extending daily exposure durations to indoor air contaminants.

This intensification of indoor presence altered traditional exposure assumptions. Rather than brief encounters with elevated pollutant concentrations, occupants experienced prolonged inhalation of lower-level emissions [29]. Such exposure profiles are particularly relevant for compounds with chronic toxicity, where cumulative dose rather than peak concentration determines health outcomes. Renovated environments thus transitioned from temporary pollution sources to continuous exposure settings.

Occupancy density within households also increased, amplifying exposure through shared air volumes and heightened resuspension of settled particulates [26]. Routine activities such as cleaning, movement, and equipment use contributed to the redistribution of pollutants within indoor spaces. In multi-occupant dwellings, individual behaviours interacted to shape collective exposure patterns.

Behavioural adaptations further influenced ventilation practices. Concerns about thermal comfort, security, and noise frequently led occupants to limit window opening, particularly in urban environments [31]. These behavioural choices, while rational within their social context, reduced pollutant dilution and increased retention. The convergence of extended indoor occupancy and constrained ventilation provides a critical link between behavioural shifts and heightened exposure intensity, setting the stage for climate- and infrastructure-specific considerations [27].

5.3 Interaction Between Ventilation, Climate, and Pollutant Retention

Ventilation effectiveness is intrinsically linked to climatic conditions, particularly in tropical environments where thermal and humidity factors shape building operation. In Nigerian buildings, natural ventilation remains the predominant strategy for air exchange, relying on window opening and passive airflow [23]. However, high ambient temperatures and humidity often discourage sustained ventilation, particularly during peak heat periods.

Tropical climate conditions influence pollutant retention through multiple pathways. Elevated temperatures accelerate VOC volatilisation, increasing emission rates from renovation materials [28]. High humidity alters surface chemistry and adsorption behaviour, potentially prolonging pollutant residence on indoor materials. These climatic influences interact with ventilation constraints to create conditions favourable for pollutant accumulation.

Limited mechanical ventilation infrastructure further compounds these effects. Where mechanical systems exist, they are frequently designed for thermal comfort rather than pollutant removal [30]. Filtration capacity may be insufficient to capture fine particulates or gaseous contaminants, allowing pollutants to circulate within indoor air. In many buildings, the absence of mechanical ventilation leaves natural airflow as the sole removal mechanism, rendering indoor air quality highly sensitive to occupant behaviour and external conditions.

The interaction between climate, ventilation, and pollutant dynamics produces spatial and temporal variability in indoor air quality [32]. Pollutant concentrations may fluctuate throughout the day, responding to temperature cycles and ventilation practices. Recognising these interactions provides a conceptual foundation for understanding indoor accumulation mechanisms and informs subsequent assessment of health impacts within climate-specific urban contexts [25].

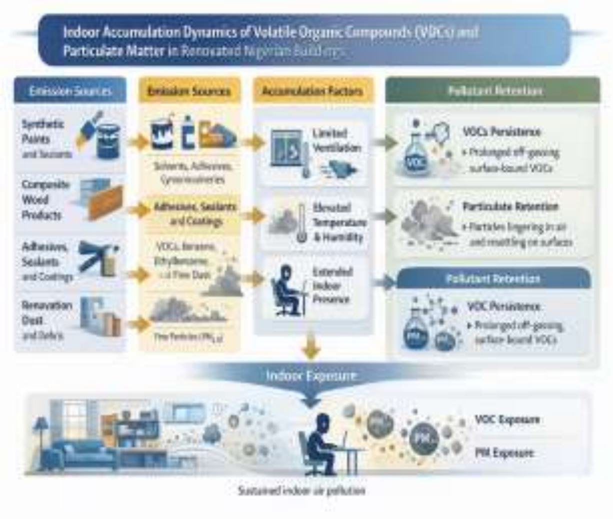

Figure 2: *Indoor accumulation dynamics of volatile organic compounds and particulate matter in renovated Nigerian buildings*

6. EVIDENCE SYNTHESIS: MEASUREMENTS, CASE OBSERVATIONS, AND RISK CHARACTERISATION

6.1 Empirical Evidence from Indoor Air Quality Studies in Similar Contexts

Empirical studies conducted in low- and middle-income urban settings provide important insights into indoor air quality dynamics relevant to Nigerian buildings. Research across diverse regions has consistently demonstrated that indoor concentrations of volatile organic compounds and particulate matter frequently exceed outdoor levels, particularly in recently renovated or poorly ventilated structures [31]. These findings challenge assumptions that indoor environments are inherently safer than outdoor spaces and underscore the significance of indoor emission sources.

Studies from rapidly urbanising cities indicate that renovation activities contribute substantially to indoor pollutant loads. Measurements conducted in residential and commercial buildings have identified elevated VOC concentrations following painting, flooring installation, and furniture replacement, with decay periods extending far beyond initial occupancy [29]. Similarly, particulate matter levels have been shown to remain elevated for prolonged periods due to dust resuspension and limited ventilation. In many cases, indoor $PM_{2.5}$ concentrations approached or exceeded levels associated with adverse health outcomes [34].

Evidence from comparable climatic regions highlights the role of temperature and humidity in shaping indoor pollutant behaviour. Tropical and subtropical studies report accelerated chemical emissions and reduced ventilation effectiveness during warmer periods, leading to higher indoor pollutant persistence [32]. These climatic influences are particularly relevant to Nigerian settings, where thermal comfort considerations often constrain natural ventilation.

Although direct measurement data from Nigerian buildings remain limited, existing studies provide transferable insights. Similar housing typologies, material choices, and ventilation practices suggest that observed patterns are likely applicable [30]. The consistency of findings across LMIC contexts supports the inference that renovation-related indoor pollution represents a systemic issue rather than an isolated phenomenon. Synthesising this evidence establishes a credible empirical foundation for contextualising Nigerian exposure scenarios [35].

6.2 Qualitative Case Observations from Nigerian Renovation Scenarios

Qualitative observations from Nigerian renovation contexts further illuminate how empirical findings translate into lived experience. In residential buildings, occupants frequently report strong odours, eye irritation, and discomfort following repainting or flooring replacement, particularly when renovations occur without temporary relocation [33]. These observations align with documented VOC emission profiles and suggest sustained exposure during early occupancy periods.

Office environments undergoing refurbishment present similar challenges. Space reconfiguration and material substitution are often conducted while operations continue, exposing workers to renovation emissions over extended workdays [29]. Limited ventilation and reliance on enclosed layouts exacerbate pollutant accumulation, especially in shared office spaces. Institutional buildings, including schools and healthcare facilities, face additional risks due to high occupant density and vulnerable populations.

Informal renovation practices are common across these settings. Decisions regarding material selection and ventilation are typically driven by cost, availability, and perceived durability rather than emission characteristics [31]. Post-renovation flushing periods are rarely observed, and awareness of indoor air quality risks remains low. These qualitative patterns reinforce the relevance of empirical findings and illustrate how structural and behavioural factors interact to shape exposure.

By grounding quantitative evidence in observable renovation practices, these case observations provide a critical bridge between measurement studies and policy considerations [35]. They highlight the practical realities that must be addressed when translating evidence into effective indoor air quality interventions.

6.3 Comparative Risk Perspective: Infection Control vs Environmental Exposure

Post-pandemic renovation decisions often reflected a prioritisation of infection control and hygiene, sometimes at the expense of broader environmental health considerations. Measures such as increased enclosure, surface sealing, and material replacement were implemented to reduce perceived infection risks [30]. While these interventions offered immediate reassurance, they also altered indoor pollutant dynamics in ways that increased chemical and particulate exposure.

This trade-off illustrates a broader tension in recovery planning. Infection control strategies tend to focus on short-term and visible risks, whereas environmental exposures produce diffuse and delayed health effects [34]. Renovation-driven indoor pollution thus represents a secondary risk pathway that remained largely unaddressed during recovery efforts.

Balancing these competing risks requires a more integrated framework that recognises indoor air quality as a determinant of long-term health resilience [32]. A comparative risk perspective underscores the need to evaluate recovery measures not only by their intended benefits but also by their unintended environmental consequences [29].

Table 2: Comparison of Intended Post-COVID Renovation Benefits versus Unintended Indoor Air Quality Risks

Renovation Objective (Intended Benefit)	Rationale and Expected Outcome	Associated Renovation Actions	Unintended Indoor Air Quality Risks	Resulting Exposure Implications
Improved hygiene and infection control	Reduce surface contamination and perceived transmission risk	Increased repainting, surface sealing, replacement of porous materials	Elevated VOC emissions from paints, sealants, and coatings	Short- and long-term inhalation exposure to chemical pollutants
Enhanced thermal comfort and energy efficiency	Reduce heat gain and improve indoor comfort	Window sealing, insulation upgrades, enclosure of open spaces	Reduced natural ventilation and pollutant dilution	Accumulation of VOCs and fine particulate matter indoors
Space reconfiguration for new work patterns	Accommodate remote work and flexible occupancy	Partitioning, ceiling modifications, furniture installation	Construction dust and off-gassing from composite materials	Prolonged low-level exposure during extended indoor occupancy
Aesthetic modernisation and building renewal	Signal recovery, resilience, and improved functionality	Flooring replacement, wall finishing, decorative upgrades	Combined VOC release and particulate resuspension	Increased cumulative exposure in frequently occupied spaces
Noise and security enhancement	Improve privacy and reduce external disturbance	Installation of sealed windows, reinforced doors	Restricted airflow and increased pollutant retention	Elevated indoor pollutant residence time
Rapid post-disruption reoccupation	Restore building use with minimal downtime	Accelerated renovation timelines with ongoing occupancy	Peak exposure during active off-gassing periods	Higher acute exposure coinciding with prolonged presence

7. POLICY, DESIGN, AND PUBLIC HEALTH IMPLICATIONS

7.1 Integrating Indoor Air Quality into Post-Pandemic Building Recovery Policies

The incorporation of indoor air quality considerations into building recovery policies represents a critical yet underdeveloped dimension of post-pandemic planning. While recovery initiatives largely focused on restoring economic activity and functional building use, indoor environmental health was rarely treated as a core public health priority [33]. This omission reflects a broader tendency to address indoor air quality reactively rather than as a structural determinant of population health.

Elevating indoor air quality within recovery frameworks requires recognising indoor environments as primary exposure settings. As individuals spend substantial portions of their daily lives indoors, renovation-related emissions can contribute meaningfully to cumulative health risk [36]. Policy approaches that prioritise infection control without parallel attention to chemical and particulate exposures risk substituting one category of health hazard for another. Integrating indoor air quality metrics into building approval, refurbishment guidelines, and occupancy certification processes would help address this imbalance.

Alignment with sustainable building agendas offers a practical pathway for policy integration. Concepts such as healthy buildings, low-emission materials, and lifecycle-based design already feature within broader sustainability discourse [34]. Embedding indoor air quality indicators within these frameworks allows environmental health objectives to complement energy efficiency and climate goals. For example, ventilation strategies that balance thermal performance with pollutant removal can support both health and sustainability outcomes.

Institutional coordination is essential for effective implementation. Public health agencies, urban planning authorities, and environmental regulators must operate within coherent governance structures that acknowledge indoor air quality as a shared responsibility [38]. Such coordination would facilitate data collection, guideline development, and enforcement. By reframing indoor air quality as a policy-relevant public health issue rather than a technical afterthought, recovery strategies can better support long-term resilience and wellbeing [35].

7.2 Material Selection, Ventilation Strategies, and Renovation Timing

Design-level interventions play a pivotal role in mitigating renovation-related indoor pollution. Material selection is among the most direct mechanisms for reducing emission sources. Low-emission paints, adhesives, and composite materials have been shown to significantly reduce indoor VOC concentrations when compared with conventional alternatives [33]. However, awareness and availability of such materials remain uneven, particularly in cost-sensitive markets.

Ventilation strategies must be considered alongside material choices. Adequate air exchange during and after renovation activities can accelerate pollutant removal and reduce exposure duration [37]. In contexts where mechanical ventilation is limited, design solutions that enhance natural airflow such as improved window placement and cross-ventilation can offer meaningful benefits. Importantly, ventilation systems should be designed to address both thermal comfort and pollutant dilution, rather than prioritising one at the expense of the other.

Renovation timing also influences exposure outcomes. Scheduling refurbishment activities during periods of reduced occupancy can limit direct exposure, while mandatory post-renovation ventilation or "flush-out" periods allow pollutant concentrations to decay before reoccupation [35]. Such measures are rarely formalised but represent low-cost strategies with significant health benefits.

Together, material selection, ventilation planning, and renovation timing form an integrated design approach to indoor air quality management. Embedding these considerations into renovation guidelines can transform design decisions into proactive public health interventions [38].

7.3 Risk Communication and Occupant Awareness

Risk communication is a critical yet often overlooked component of indoor air quality management. Occupants frequently lack information about potential health risks associated with renovation materials and practices [36]. Without accessible guidance, individuals may unknowingly increase exposure through prolonged occupancy or inadequate ventilation.

Effective communication strategies should provide clear, actionable information to residents and building users. Simple guidance on ventilation practices, material choices, and post-renovation waiting periods can empower occupants to reduce exposure [34]. Communication efforts are most effective when tailored to local contexts and delivered through trusted channels.

Enhancing occupant awareness also supports policy implementation by creating demand for healthier building practices. Informed users are more likely to advocate for low-emission materials and improved ventilation, reinforcing regulatory objectives [33]. Strengthening risk communication thus provides a natural transition toward future research and implementation strategies aimed at sustaining indoor environmental health improvements [38].

Figure 3: *Policy and design intervention framework for reducing renovation-related indoor air pollution*

8. FUTURE RESEARCH DIRECTIONS AND IMPLEMENTATION CHALLENGES

8.1 Data Gaps and Monitoring Needs in Nigerian Buildings

A persistent limitation in addressing indoor air quality risks in Nigerian buildings is the absence of systematic data collection and monitoring infrastructure. Indoor air quality surveillance remains fragmented, with most environmental monitoring efforts focused on outdoor pollution sources [36]. As a result, renovation-related indoor exposures are rarely quantified, leaving significant uncertainty regarding pollutant concentrations, exposure duration, and population-level health impacts.

The lack of routine indoor monitoring limits the ability to establish baseline conditions or evaluate the effectiveness of mitigation strategies. Low-cost sensor technologies and portable monitoring devices offer potential pathways for expanding indoor air quality assessment, yet their deployment remains limited by technical capacity and institutional prioritisation [39]. Without consistent measurement, indoor pollution remains an abstract concern rather than a measurable public health indicator.

Longitudinal exposure studies are particularly needed to capture the cumulative effects of renovation-related emissions. Short-term assessments often fail to account for prolonged off-gassing, behavioural adaptations, and seasonal variability [37]. Longitudinal designs would enable examination of exposure trajectories over time and facilitate linkage with health outcomes. Such studies are essential for distinguishing transient exposure events from chronic indoor pollution patterns.

Addressing these data gaps requires coordinated investment in monitoring infrastructure and research capacity. Integrating indoor air quality indicators into existing environmental and public health surveillance systems would improve visibility and support evidence-based decision-making [41].

8.2 Translating Evidence into Enforceable Building Practices

Even where evidence of indoor air quality risks exists, translating research findings into enforceable building practices presents substantial challenges. Institutional responsibilities for building regulation, environmental protection, and public health are often dispersed across multiple agencies, limiting coordinated action [38]. This fragmentation complicates the development and enforcement of indoor air quality standards.

Capacity constraints further impede implementation. Regulatory agencies may lack technical expertise, inspection resources, or training to assess indoor air quality risks associated with renovation activities [40]. In informal construction contexts, enforcement mechanisms are particularly weak, as renovations frequently occur outside formal approval processes. These realities create a gap between policy intent and on-the-ground practice.

Compliance challenges are also shaped by economic considerations. Building owners and occupants may prioritise affordability and speed over environmental performance, particularly in the absence of clear regulatory requirements [36]. Without incentives or enforcement, adoption of low-emission materials and ventilation best practices remains voluntary and inconsistent.

Bridging this implementation gap requires strengthening institutional coordination and aligning incentives with public health objectives. Evidence-informed guidelines must be accompanied by capacity-building initiatives, clear accountability structures, and mechanisms for compliance monitoring [41]. Addressing these challenges is essential for converting research insights into durable improvements in indoor environmental health.

9. CONCLUSION

9.1 Summary of Key Insights and Contributions

This article has examined the unintended indoor air quality consequences associated with building renovation practices adopted during periods of societal disruption, with a particular focus on volatile organic compound and particulate matter exposure. The analysis demonstrates that renovation-driven emissions represent a significant yet under-recognised source of indoor pollution, shaped by material choices, construction practices, and altered occupancy patterns. Rather than being short-lived disturbances, these emissions often persist over extended periods, creating sustained exposure environments within enclosed indoor spaces.

A central contribution of this work lies in its integration of building science, environmental health, and urban governance perspectives. By tracing pollutant pathways from renovation activities through indoor accumulation mechanisms and health implications, the article highlights how well-intentioned recovery actions can generate secondary environmental risks. The emphasis on cumulative exposure and prolonged indoor presence underscores the importance of moving beyond episodic assessments of indoor pollution.

The Nigerian context provides critical insight into how structural factors amplify these risks. High-density housing, reliance on natural ventilation, informal construction practices, and limited regulatory oversight collectively intensify indoor pollutant retention and exposure. These conditions are not unique to Nigeria but are representative of challenges faced in many rapidly urbanising settings. By situating renovation-related indoor air quality risks within this context, the article contributes to a broader understanding of how global recovery dynamics intersect with local environmental vulnerabilities.

9.2 Final Reflections on Post-COVID Built Environment Resilience

The findings underscore a broader lesson for built environment resilience: addressing one public health risk should not inadvertently create another. Renovation strategies aimed at improving comfort, hygiene, or functionality can undermine long-term health if indoor air quality considerations are neglected. This substitution of risks reflects fragmented planning approaches that separate building design from environmental health outcomes.

Achieving resilient indoor environments requires integrated governance that recognises buildings as continuous exposure settings rather than neutral containers for human activity. Policies, design practices, and institutional frameworks must align to balance infection control, environmental sustainability, and indoor air quality protection. By embedding health-oriented criteria into renovation and recovery planning, decision-makers can avoid repeating cycles of unintended harm.

Ultimately, strengthening the relationship between building practice and public health is essential for creating indoor environments that support wellbeing under both routine and crisis conditions.

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