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Review Article

Architectural contributions to air pollution and design-based mitigation in Enugu, Nigeria: a typological review

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Abstract

Air pollution is usually discussed as a problem of industry, transport and energy supply, yet the built environment also shapes emissions, pollutant dispersion and occupant exposure. This paper reframes architecture as an active mediator of air pollution in rapidly urbanising Nigerian cities, using Enugu as a contextually grounded case. The study adopts a narrative literature review combined with typological analysis of common urban building forms observed in Enugu, including street-front commercial buildings, sealed office blocks, mixed-use buildings, residential compounds and flats, institutional buildings and industrial sheds. The paper develops a micro-macro space framework to explain how design decisions at individual sites accumulate into neighbourhood- and city-scale air-quality outcomes. The review suggests that architecture may contribute to air-pollution exposure through three interrelated pathways: urban form and microclimate, building systems and materials, and construction and operational practices. In Enugu, these pathways are intensified by generator dependence, road-facing commercial frontages, poor intake placement, weak ventilation design, high-emission finishes, inadequate waste zoning and dusty construction processes. The paper contributes a building-typology exposure matrix and an architecture-led mitigation framework covering site planning, vegetation buffers, passive cooling, mixed-mode ventilation, filtration, low-emission materials, generator zoning, construction dust control and post-occupancy air-quality checks. The study argues that air-pollution mitigation should be integrated into architectural design review and building approval processes, not treated solely as an environmental-management issue after construction. The paper contributes a coherent conceptual basis for integrating air-quality concerns into architectural site planning, building design and regulatory review in Enugu and comparable hot-humid African cities.

Keywords: air pollution; architecture; indoor air quality; sustainable architecture; building typology

Highlights

- Architecture acts as an active mediator of air pollution by shaping emissions, pollutant dispersion, indoor infiltration & human exposure in urban buildings.
- Enugu building types show different pollution-risk levels.
- Key architectural contributors to air pollution include poor site planning, weak ventilation design, generator placement, high-emission materials, construction dust, inadequate waste zoning and limited landscape buffering.

1 Introduction

Air pollution is a major public-health and environmental challenge, particularly in rapidly urbanising cities where traffic emissions, generators, construction dust, open waste burning, and poorly ventilated buildings operate together. The World Health Organization reports that most of the global population breathes air that exceeds health-based guideline limits, while fine particulate matter and gaseous pollutants continue to be linked with respiratory, cardiovascular, and premature-mortality outcomes (World Health Organization, 2021, 2022; Vardoulakis et al., 2015). Although urban air-pollution debates often emphasise transport and industry, built-environment research increasingly shows that building design and urban morphology influence pollutant concentration, dispersion, infiltration, and occupant exposure (Edussuriya et al., 2011; Miao et al., 2020; Zhang et al., 2018; Zhou et al., 2022). These risks are not limited to outdoor streets or industrial zones; they also occur inside the buildings where people spend most of their daily lives. The building sector is central to this problem therefore architecture cannot be treated as a neutral background to air-pollution problems.

Architecture affects air quality in two related ways. First, buildings generate or intensify pollutants through operational energy demand, backup power generation, construction activities, material emissions, and poor waste management (Azarmi et al., 2014; Cabeza et al., 2014; Lützkendorf & Balouktsi, 2022; Mannan & Al-Ghamdi, 2021). Second, buildings mediate exposure by shaping the relationship between outdoor air, indoor air, and human occupation. Window type, internal layout, headroom, envelope permeability, ventilation mode, air-intake placement, filter rating, and maintenance influence whether pollutants are diluted, filtered, recirculated or accumulated indoors (Allen et al., 2016; Ben-David & Waring, 2016; Jones et al., 2021; Sundell et al., 2011).

The Nigerian context makes this relationship particularly important. Intermittent public electricity supply has normalised the use of petrol and diesel generators around homes, commercial premises, institutions, and workshops. At the same time, tropical heat, harmattan dust, increasing urban density, roadside trading, weak waste management and limited indoor air-quality regulation expose occupants to overlapping indoor and outdoor pollutant sources. Evidence from Nigerian cities indicates that residential and office indoor air quality is affected by outdoor particulate matter, fuel choice, waste disposal, window typology, seasonal conditions, and architectural features (Basil et al., 2024; Jelili et al., 2020; Toyinbo et al., 2019; Uzuegbunam et al., 2018).

Enugu, a growing city in south-eastern Nigeria, provides a useful lens for this discussion. Its commercial streets, mixed-use corridors, institutional compounds, low-rise residential neighbourhoods and industrial edges display building forms that are typical of many tropical African cities. The problem is not only that buildings receive polluted air from roads or generators, but also that architectural choices can trap pollutants, admit them at breathing level, increase cooling loads, and encourage the use of additional fossil-fueled equipment. This paper therefore asks: how does architecture contribute to air pollution at building and neighbourhood scales, and what design measures can reduce emissions and exposure without relying primarily on expensive mechanical systems? The article makes three contributions. It synthesises the mechanisms through which architecture contributes to air pollution; it develops a micro-macro framework linking plot-level design decisions to urban-scale air-quality effects; and it proposes a context-specific typology and design response for Enugu that can inform sustainable architecture teaching, professional practice and building-control review in similar urban settings.

2 Literature Review

2.1 Architecture, energy demand and emission pathways

The building sector is a major driver of energy demand and carbon emissions across both operational and embodied stages. Life-cycle studies show that buildings consume energy through heating, cooling, lighting, ventilation, equipment, and material production, while embodied impacts arise from extraction, processing, transportation, installation, maintenance, and end-of-life processes (Anand & Amor, 2017; Cabeza et al., 2014; Chastas et al., 2016; Dixit et al., 2010; Ramesh et al., 2010). Although carbon dioxide is not the same as local air pollution, the same design choices that increase energy demand often increase combustion-related pollutants when electricity is supplied by diesel generators or fossil-fuelled grids. In tropical cities, excessive solar heat gain, poor shading, weak cross-ventilation, and inefficient cooling therefore contribute indirectly to outdoor concentrations of carbon monoxide, nitrogen oxides, and particulate matter (Mba et al., 2023).

Embodied emissions also matter because emissions arise from material production and construction as well as from building operation (World Green Building Council, 2019). Cement, steel, aluminum, glass, and synthetic finishes are associated with energy-intensive production and construction processes (Pomponi & Moncaster, 2016; Lützkendorf & Balouktsi, 2022). On building sites, excavation, demolition, cutting, mixing, stockpiling, and hauling release coarse and fine particles, while diesel-powered equipment contributes black carbon and nitrogen oxides (Azarmi et al., 2014; Yan et al., 2023). Where construction sites lack water suppression, material covering, wheel washing, and waste-control measures, dust is transported beyond the site boundary and becomes a neighbourhood-level exposure problem.

2.2 Urban morphology, street canyons, and microclimate

Urban morphology shapes how air moves around buildings. Street-canyon studies show that the relationship between building height, street width, wind direction, facade continuity, and obstacle placement determines whether pollutants disperse or remain trapped at pedestrian level (Buccolieri et al., 2018; Cui et al., 2021; Edussuriya et al., 2011; Miao et al., 2020). Deep or poorly ventilated canyons can encourage recirculation zones where vehicle and generator emissions remain close to the breathing zone. Urban morphology can also alter heat storage and ventilation, increasing thermal stress and indirectly raising energy demand for cooling (Ng, 2009; Zhang et al., 2018). This urban-scale literature is directly relevant to architectural site planning. Setbacks, boundary walls, arcades, service yards, generator locations, ground-floor permeability, courtyard placement, and landscape design are usually decided at the plot or building scale, but their effects accumulate across streets and districts. The implication is that air quality is not only an environmental engineering concern. It is also an architectural-design concern because the architect shapes the micro-spaces through which air, heat, and pollutants move.

2.3 Indoor air quality, ventilation, and material emissions

Indoor air quality depends on the interaction between outdoor pollution, indoor sources, ventilation, filtration, humidity, temperature, and occupant behaviour (Mannan & Al-Ghamdi, 2021; Morawska et al., 2017; Nazaroff, 2013). Seasonal variation can also influence indoor air quality and thermal conditions in occupied buildings, including changes in CO₂, particulate levels, formaldehyde, temperature, and relative humidity (Deng & Lau, 2019). People spend most of their time indoors, making the indoor environment a critical exposure setting rather than a neutral refuge from outdoor air pollution (Klepeis et al., 2001; Sundell

et al., 2011). Elevated indoor CO₂ is commonly associated with inadequate ventilation and pollutant accumulation, although evidence concerning the direct cognitive effects of CO₂ remains mixed (Du et al., 2020). Indoor sources include cooking, cleaning products, furnishings, paints, adhesives, sealants, office equipment, dampness, and combustion appliances. Synthetic materials and finishes may release volatile organic compounds and formaldehyde, sometimes for extended periods after installation (Salthammer et al., 2010; Wolkoff, 2013; Yu & Crump, 1998).

Ventilation is central but complex. Experimental office studies have shown that increasing outdoor-air supply can improve perceived air quality and some measures of occupant performance (Wargocki et al., 2000). Increased outdoor-air supply can dilute indoor-generated pollutants, yet it may also introduce outdoor PM_{2.5}, nitrogen oxides, or dust if the intake is located near roads, waste areas, or generator exhausts (Ben-David & Waring, 2016; Persily, 2015). Office studies show that efficient filtration can reduce indoor PM_{2.5}, with higher-rated filters performing better than low-efficiency filters when systems are properly maintained (Belias et al., 2022; Jones et al., 2021). Natural ventilation remains important in tropical Nigerian buildings, but it should be deliberately designed through orientation, opening size, cross-ventilation paths, protected intakes, shaded facades, and pollutant-source separation.

2.4 Green infrastructure and passive design

Green infrastructure can reduce exposure by deposition, barrier effects, shading, evapotranspiration, and microclimate moderation, but its performance is highly context-dependent (Abhijith et al., 2017; Diener & Mudu, 2021; Kumar et al., 2024). In open-road settings, trees and hedges may intercept particulates and separate people from traffic emissions. In narrow street canyons, however, dense tree canopies can reduce ventilation and trap pollutants if poorly placed (Abhijith et al., 2017; Buccolieri et al., 2018). Green walls, hedges, permeable surfaces, and planted courtyards may be more suitable in some constrained sites because they provide filtering and cooling without obstructing the whole canyon air path.

Passive design complements green infrastructure. Correct orientation, shading, envelope design, roof insulation, thermal mass, ventilation zoning, and daylight control reduce heat gains and cooling demand, thereby reducing reliance on generators in contexts where electricity supply is unreliable (Frontczak & Wargocki, 2011; Santamouris, 2014). In hot-humid regions, passive strategies must balance cooling, ventilation, and humidity control. Design responses should therefore be typology-specific rather than reduced to a single prescription such as adding trees or increasing window area.

2.5 Evidence from Nigeria and the Enugu research gap

Nigerian indoor-air studies show that pollutant exposure is shaped by building characteristics, seasonal conditions, domestic energy practices, and outdoor sources (Auwalu, 2026). Toyinbo et al. (2019) linked Nigerian school environments with dampness, building condition, and pollution-source proximity, while Jelili et al. (2020) found that indoor and outdoor particulate matter in Ogbomoso varied with residential zones, fuel use, and waste-disposal practices. In Enugu, Basil et al. (2024) demonstrated that architectural features in government offices explained a substantial proportion of indoor air-quality variation, with window typology and seasonal differences influencing air-quality outcomes. Mba et al. (2024) did a post-occupancy evaluation on the impact of building plan shape on natural ventilation efficiency for thermal comfort in educational facilities of tropical environments. These studies support the argument that architectural choices are measurable exposure modifiers, but there remains a need for a broader framework that

connects building types, site planning, operational practices, and micro-scale urban form (Oforji et al., 2026). This paper responds to these gaps by developing a typological and design-oriented framework rather than claiming to present a new field-measurement campaign. Its contribution is a structured explanation of how architectural choices contribute to air pollution, a classification of Enugu building types by likely exposure pathway, and a practical mitigation framework that can inform design, teaching, policy and future empirical research.

3 Methodology

3.1 Research design

This paper adopts a qualitative, evidence-informed review and typological-analysis design. It is not presented as a primary air-quality monitoring study. Rather, it synthesises relevant literature, policy evidence, and contextual observations from Enugu to develop a framework that can guide architectural design and future empirical testing. This design is appropriate because the main research problem is conceptual and applied: how architectural decisions contribute to or mitigate air-pollution exposure in a specific urban context. The methodology follows four stages. First, the paper reviews literature on air pollution, indoor air quality, building energy demand, street canyon effects, ventilation, filtration, construction dust, material emissions, and green infrastructure. Second, it identifies architectural mechanisms through which pollutants are generated, trapped, transferred, or diluted. Third, it classifies common building typologies in Enugu based on form, use, ventilation strategy, and proximity to pollution sources. Fourth, it translates the analysis into a design-based mitigation framework for architects, clients and building-control agencies.

3.2 Study context: Enugu, Nigeria

Enugu is a hot-humid city in southeastern Nigeria with mixed residential, commercial, institutional, and industrial land uses. The paper focuses on urban districts and corridors in the city, including Ogui Road, Zik Avenue, Achara Layout, New Haven, GRA, Abakpa, Trans-Ekulu, Emene and 9th Mile. These areas illustrate the diversity of building forms and exposure situations in the city: street-front commercial shops, sealed offices, shop-house mixed-use blocks, compound houses, flats, schools, hospitals, churches, markets, workshops, and industrial sheds (Okeke et al., 2020). The Enugu context is particularly useful because several pollution pressures overlap (Okeke et al., 2021). Traffic emissions, generator use, harmattan dust, construction activity, open waste burning, high occupancy, and hot-humid weather conditions interact with architectural decisions. A building with inadequate setbacks, poorly placed openings, high solar gain, and a generator beside the entrance may simultaneously worsen outdoor emissions, indoor exposure, and cooling demand. The study therefore treats Enugu as a contextual case for developing a transferable design framework.

Contextual observations were used only to identify recurring building typologies and exposure situations in Enugu. They were not treated as a statistically representative building survey. The listed districts were selected because they contain common combinations of commercial, residential, institutional, and industrial building forms found in the city. The typological categories should therefore be interpreted as analytical examples requiring future empirical validation.

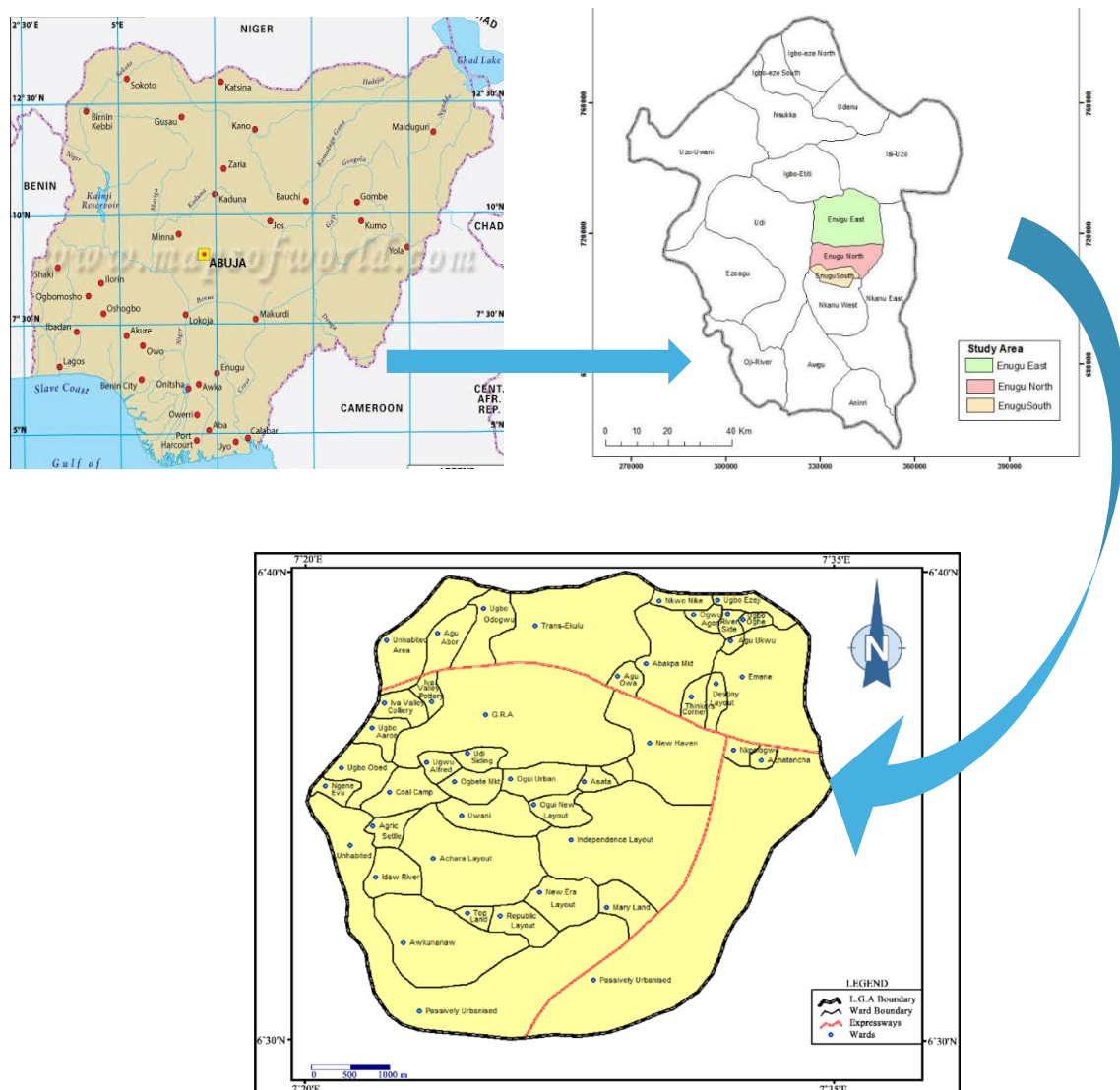


Figure 1. Location of Enugu metropolis, southeastern Nigeria, showing the study context. Source: Okeke et al., 2021.

3.3 Literature selection

The literature review focused on studies addressing five themes: indoor air quality in buildings; urban morphology and pollutant dispersion; construction-related particulate emissions; building materials and volatile organic compounds; and green infrastructure/passive-design mitigation. Searches were undertaken across major academic databases and journal platforms, including Web of Science, Scopus, Google Scholar, and publisher websites. Search phrases combined terms such as 'architecture and air pollution,' 'indoor air quality buildings,' 'urban street canyon pollutant dispersion,' 'green infrastructure air pollution,' 'construction dust PM2.5,' 'ventilation filtration office buildings,' 'Nigeria indoor air quality,' and 'Enugu indoor air quality.' Priority was given to peer-reviewed journal articles, review papers, and empirical studies published between 2000 and 2026, while earlier foundational studies were retained where they remained influential. Studies were included when they addressed architectural, urban-design, building services, or material factors influencing air pollution or exposure. Studies were excluded when they focused solely on atmospheric chemistry without design implications, transport emissions without built-form relevance, or medical outcomes without environmental exposure pathways. Institutional sources, including WHO (2021), IPCC (2022), and WorldGBC reports

(2019), were used only for contextual framing and were not counted as evidence of architectural mechanisms. To improve transparency, the review followed a structured narrative procedure. Search results were first screened by title and abstract, then by full-text relevance to architectural design, indoor air quality, urban morphology, construction dust, ventilation, materials, or green infrastructure. Studies were retained only where they provided evidence linking built-form decisions to pollutant generation, dispersion, infiltration, or exposure. Future versions of this framework should adopt a full systematic review protocol, including a PRISMA flow diagram, database-specific search strings, and quality appraisal.

3.4 Analytical procedure

The analytical procedure used a source-pathway-receptor logic. For each building typology, the analysis asked: (i) (i) what pollutants are likely to be generated or admitted; (ii) which architectural features create or intensify exposure pathways; (iii) which occupants or surrounding users are most exposed; (iv) operational energy demand; and (v) what design strategies can reduce exposure without relying solely on expensive mechanical systems. The typology was then refined into six categories that reflect common Enugu conditions: Type A: street-front commercial; Type B: sealed office/commercial; Type C: mixed-use; Type D: residential compound/flats; Type E: institutional/public; and Type F: industrial/workshop buildings. Because no new measurement campaign was undertaken, the exposure categories used in the tables—low, moderate, high, and very high - are interpretive risk categories rather than measured concentration values. This distinction is important for technical accuracy. The categories indicate likely exposure risk based on building form, source proximity, ventilation pathway and occupancy profile. They should be validated in future studies using sensor measurements of PM_{2.5}, PM₁₀, CO, CO₂, NO₂, TVOCs, formaldehyde, temperature, relative humidity, wind speed and occupancy.

3.5 Scope and limitations

The paper is limited to architectural and urban-design mechanisms. It does not model atmospheric chemistry, quantify emissions inventories, measure pollutant concentrations or perform statistical analysis. The building typologies are derived from contextual observation and literature synthesis rather than from a sampled survey of all buildings in Enugu. Also due to ethic reasons, photographs are not collected. The recommendations should therefore be read as design and policy propositions requiring empirical validation. Nevertheless, the framework is valuable because it converts a broad environmental-health problem into architectural decisions that can be addressed during site planning, design review, construction and post-occupancy management.

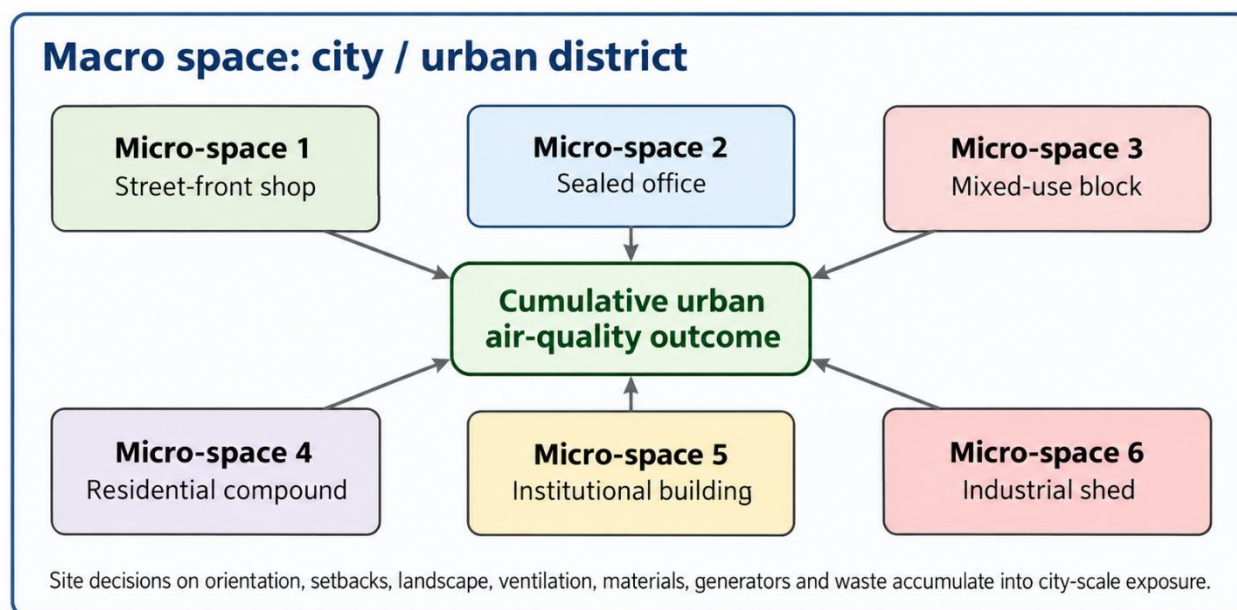


Figure 2. Micro-macro space framework for architectural air-pollution control. Source: Author conceptualisation, 2026.

4 Results- Key Findings

4.1 Architectural pathways linking buildings to air pollution

The synthesis identifies seven pathways through which architecture contributes to air pollution and exposure. These are summarised in Table 1. The most important finding is that the problem is not confined to one design element. Air quality is shaped by the interaction of site planning, urban form, material specification, operational systems, construction management and maintenance.

Table 1. Architectural pathways through which buildings generate, modify or mitigate air-pollution exposure.

Pathway	Architectural mechanism	Principal pollutants/exposure issue	Typical Enugu manifestation	Design implication
Urban form and site planning (Edussuriya et al., 2011; Miao et al., 2020)	Deep street canyons, minimal setbacks, continuous street walls, hard paving, poor service-zone location	Trapping of PM2.5, PM10, CO and NOx at pedestrian level; heat build-up	Road-facing shops and commercial blocks along busy corridors; stagnant pedestrian zones during peak traffic	Protect wind paths, increase permeability, separate generators/waste areas from occupied spaces and intakes
Envelope and orientation (Santamouris, 2014; Mba et al., 2023)	Unshaded glazing, poor orientation, weak facade control	Higher indoor heat and cooling load; greater generator use and combustion emissions	Open-front shops and mixed-use blocks with windows/doors facing roads and generator areas	Orient long facades to minimise solar gain, add shading, insulation and reflective/cool surfaces
Ventilation and filtration (Jones et al., 2021)	Poor cross-ventilation, intakes close to roads/generators, low-efficiency or poorly maintained filters	Outdoor pollutants drawn indoors; CO2/VOCs recirculated; PM not captured	Sealed offices and banks relying on AC with intakes close to ground-level roads or generators	Design protected intakes, cross-ventilation paths, adequate exhaust and filtration appropriate to outdoor air quality
Materials and finishes (Okeke et al., 2024)	High-emission paints, adhesives, sealants, particleboard, synthetic furnishings	VOCs, formaldehyde, odour and occupant irritation	Rapid fit-outs and early occupation of offices, shops and institutional interiors	Specify low-VOC finishes, allow curing/flushing-out, use locally available low-emission materials
Building operation	Diesel/petrol generators, air-	CO, NOx, PM, black carbon and noise;	Frequent use of generators in commercial,	Reduce cooling loads; locate exhausts downwind

(Mannan & Al-Ghamdi, 2021; IPCC, 2022)	conditioning dependence, poor maintenance	high indoor CO ₂ where windows remain closed	residential and institutional buildings; generators placed near windows, balconies, corridors, shops or courtyards; poorly serviced AC systems	and above breathing level; encourage renewables
Construction activity (Yan et al., 2023)	Excavation, demolition, cutting, stockpiles, haul roads and onsite burning	PM ₁₀ , PM _{2.5} , silica dust, VOCs, smoke and diesel exhaust	Construction sites on busy streets without dust screens, water suppression or material covering; uncovered sand/cement stockpiles; cutting and demolition dust affecting adjacent shops and pedestrians	Require dust-control plans, covered materials, no open burning, equipment maintenance and phased cleaning
Landscape and drainage (Kumar et al., 2024)	Absence of vegetation, impermeable paving, stagnant drains and uncovered waste	Dust resuspension, bioaerosols, mould, odour and heat-island effects	Paved compounds with little vegetation, open drains blocked with refuse, stagnant water around buildings, dusty unpaved edges and waste storage close to occupied spaces	Use vegetated buffers, permeable paving, drains with maintenance access, shaded courtyards and waste zoning

4.2 Building typologies and relative exposure risk in Enugu

Six typologies are proposed for Enugu because they represent common combinations of form, use and exposure. The typology is not intended to replace field measurement; rather, it offers a structured way of identifying where design intervention should begin. Table 2 links each typology to its main sources, exposure mechanisms and priority design response.

Table 2. Conceptual building typology for air-pollution exposure in Enugu.

Type	Examples in Enugu	Typical form	Likely exposure mechanism	Exposure risk	Design priority
Type A: Street-front commercial	Shops along Ogui Road, Zik Avenue, Market Road	1-3 storey, open frontage, shallow setback, generator often near entrance	Direct intake of traffic emissions, generator exhaust and dust through open frontage; pedestrian-level exposure	Very high	Create vegetated setbacks; relocate generators downwind; use screened entrances; reduce open-front exposure; improve shading and cross-ventilation
Type B: Sealed office/commercial	GRA offices, banks, standalone office blocks	2-5 storey, sealed envelope, air-conditioned spaces	Exposure depends on outdoor-air intake height, filtration, maintenance and source proximity; risk of CO ₂ and VOC accumulation	Low to moderate, but high if intakes are poorly located	Protect intakes from roads/generators; specify effective filtration; provide fresh-air control; monitor CO ₂ and PM _{2.5} ; maintain HVAC systems
Type C: Mixed-use	Shop below with flats above in Achara Layout, New Haven and similar districts	Ground-floor commercial use with upper residential floors	Ground floor receives traffic/generator emissions; upper floors may experience stack transfer; cooking and domestic sources add indoor pollutants	High at ground floor, moderate above	Separate commercial and residential ventilation; locate kitchens and generators away from living spaces; provide vertical ventilation and source control
Type D: Residential compounds and flats	Traditional compounds in Abakpa, modern flats in Trans-Ekulu	Detached houses, compound layouts, 2-4 storey flats	Indoor cooking fuels, nearby generators, bush burning, dust and poor drainage; AC flats may recirculate VOCs and CO ₂	Low to medium but source-dependent	Promote clean cooking, shaded cross-ventilation, generator setbacks, courtyard planting, drainage and low-emission finishes

Type E: Institutional/public	Schools, hospitals, churches, markets	Large floor plates, high occupancy, variable ventilation	High occupancy drives CO ₂ build-up; sensitive users are exposed to road dust, generator exhaust and poor waste handling	Variable; high for vulnerable groups	Prioritise ventilation, filtration, protected intakes, occupancy management, waste zoning and routine IAQ checks
Type F: Industrial/workshop	Factories, warehouses, workshops, mechanic villages in Emene, Trans-Ekulu and 9th Mile corridors	Open or semi-enclosed sheds, large floor plates, metal roofs, on-site generators/processes	Process dust, welding fumes, solvents, diesel exhaust, material handling and poor stack height disperse pollutants at breathing level	Very high to extreme	Separate industrial/residential uses; control dust and fumes; raise exhaust discharge; improve worker ventilation; enforce waste and solvent management

4.3 Micro-macro framework

The micro-macro framework in Figure 2 interprets the city as a cumulative system of architectural micro-spaces. Each plot, frontage, courtyard, service yard, roof, setback and ventilation opening is small in isolation, yet repeated across the city they influence heat, airflow, pollutant dispersion and exposure. A single poorly located generator or unshaded sealed facade may appear minor, but thousands of similar decisions create a macro-scale pollution burden.

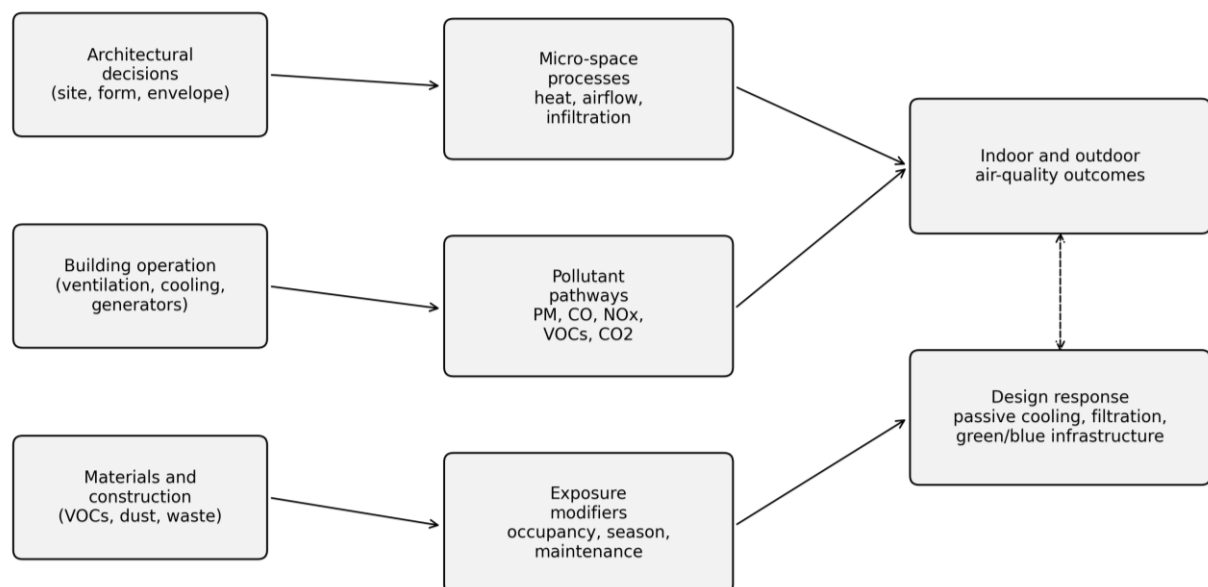


Figure 3. Micro-macro framework linking architectural decisions with air-pollution generation, exposure and mitigation.

4.4 Design-based mitigation framework

The results suggest that pollution mitigation should be integrated into ordinary architectural decisions rather than added after construction. Table 3 links design actions to the pollution pathway they address.

Table 3. Architecture-led air-pollution mitigation framework for Enugu and comparable tropical cities.

Design domain	Recommended action	Pollution pathway addressed	Expected benefit
Site planning	Provide 3-5 m vegetated buffers where plots face major roads; avoid locating entrances and air intakes beside roads, waste areas or generators	Outdoor-to-indoor pollutant transfer; pedestrian exposure	Reduces direct intake of PM, CO and NO _x ; improves comfort and pedestrian microclimate
Generator zoning	Place generators downwind of occupied rooms and air intakes; use acoustic/ventilated enclosures; discharge exhaust above breathing height	Local point-source emissions	Reduces indoor CO and PM exposure and prevents exhaust recirculation into occupied areas
Passive cooling	Optimise orientation, shading, window-to-wall ratio, roof insulation and thermal mass for hot-humid conditions	Cooling demand and generator dependence	Lowers AC runtime and generator use while improving comfort
Ventilation strategy	Use cross-ventilation where outdoor air is acceptable; use mixed-mode ventilation with filtration where outdoor pollution is high	CO ₂ , VOCs, PM _{2.5} , heat stress	Balances fresh air, thermal comfort and pollution control
Material specification	Specify low-VOC paints, sealants, adhesives, boards and finishes; allow curing and pre-occupancy flush-out	Indoor VOCs and formaldehyde	Reduces indoor chemical exposure after construction and fit-out
Green/blue infrastructure	Use courtyards, shade trees, living walls, permeable paving, grassed parking and rain gardens without blocking ventilation corridors	Heat island, dust resuspension, PM deposition	Cools microclimate, reduces dust and supports pollutant deposition
Construction management	Use water suppression, covered stockpiles, wheel washing, waste segregation, no open burning and reduced idling	Construction PM, diesel exhaust and waste emissions	Controls short-term but intense exposure around active sites
Post-occupancy management	Conduct IAQ checks for PM _{2.5} , CO ₂ , CO, TVOCs, temperature and humidity before and after occupation	Performance verification	Creates feedback for maintenance, retrofits and future design decisions

The framework emphasises low-cost and enforceable interventions because many Enugu buildings operate in contexts where high-technology solutions may be difficult to maintain. However, passive design should not be understood as simply opening buildings to the outside. In polluted streets, natural ventilation must be paired with source separation, vegetation buffers, protected openings, shading, and, where necessary, mechanical filtration. Similarly, green infrastructure should be designed to improve airflow and deposition, not to create stagnant pockets in already narrow streets. The key result is therefore not a single technical solution but a hierarchy of design control: remove or reduce the pollution source where possible; separate sources from occupied spaces; interrupt exposure pathways; protect sensitive receptors; and verify performance after occupation. This hierarchy translates environmental-health thinking into architectural practice.

4.5 Relative exposure profile

The relative exposure scores were assigned using four qualitative criteria: proximity to pollution sources, degree of ventilation control, occupancy vulnerability, and likelihood of pollutant accumulation. A score of 1 indicates low source proximity and good ventilation control; 2 indicates limited exposure under normal use; 3 indicates moderate exposure depending on operation and maintenance; 4 indicates high exposure due to frequent source proximity or weak ventilation control; and 5 indicates very high exposure where occupants are close to active sources and ventilation or source separation is poor. These scores are not measured concentration values and should be validated through future monitoring.

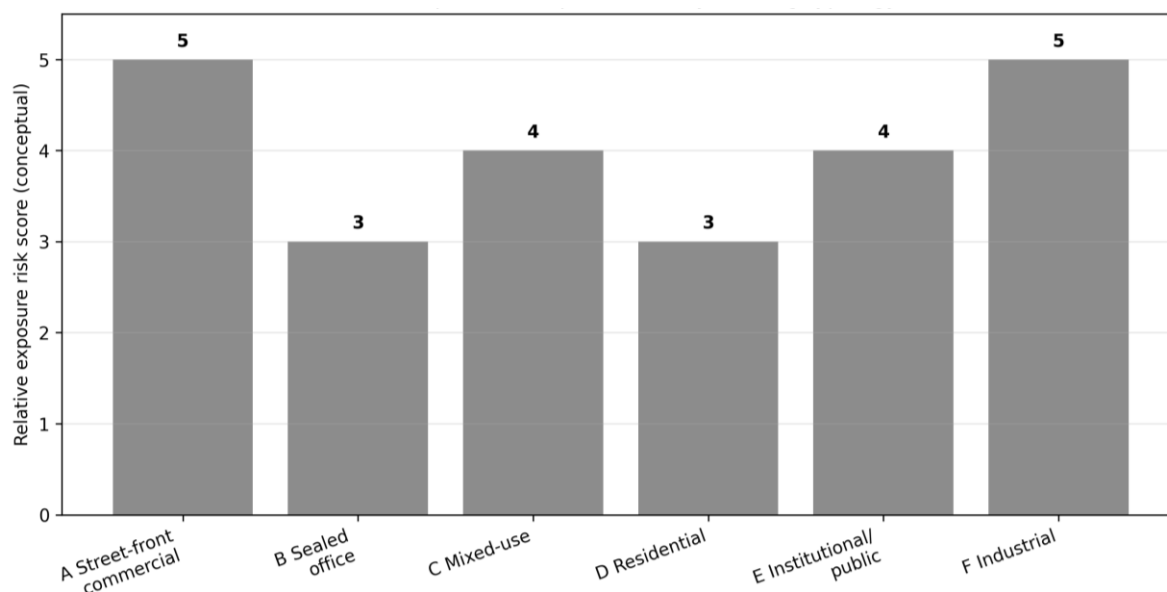


Figure 4. Relative pollution-exposure risk by building typology. Scores are conceptual indicators for design prioritisation, not measured pollutant concentrations.

Figure 4 summarises the conceptual risk scores across the six typologies. Street-front commercial buildings and industrial/workshop buildings are assigned the highest risk because occupants and pedestrians are close to active emission sources and because ventilation is often uncontrolled. Sealed offices have lower direct infiltration but may accumulate CO₂, VOCs, and recirculated particulates if outdoor-air intake and filtration are poorly managed. Institutional buildings require special attention because schools, hospitals, and worship/market spaces combine high occupancy with vulnerable users or intense short-term exposure.

5 Discussion

5.1 Architecture as an active exposure mediator

The findings reposition architecture from a passive background condition to an active exposure mediator. This is important because many air-pollution interventions concentrate on emission reduction at a regional scale but overlook the design decisions that determine exposure at the point of breathing (Zhou et al., 2022; Jones et al., 2021). Street-canyon research demonstrates that building height-to-width ratio, facade continuity, wind direction, and obstacles affect pollutant recirculation, while indoor air-quality research shows that windows, ventilation, and filtration determine whether outdoor pollution becomes indoor exposure (Cui et al., 2021; Miao et al., 2020). In Enugu, where generator exhaust, road dust, and seasonal harmattan particles are common, architecture can either expose occupants directly to pollutants or create protective micro-environments (Okeke et al., 2021). This argument does not imply that architecture alone can solve urban air pollution. Transport regulation, cleaner fuels, industrial controls, and waste management remain essential. However, the review shows that architecture determines the effectiveness of these wider interventions at the scale of daily life. A site with good airflow, shaded facades, separated service zones, low-emission materials, and appropriate ventilation will reduce exposure even before citywide air-quality infrastructure becomes fully effective.

5.2 Typology-specific implications for Enugu

The proposed typology highlights why generic design recommendations are insufficient. Type A street-front commercial buildings require source separation, frontage design, and low-level green barriers more than fully sealed envelopes. Type B sealed offices require controlled outdoor-air intake, filtration and maintenance rather than simply increasing operable windows. Type C mixed-use buildings need vertical separation of ventilation paths so that commercial fumes, generators and cooking emissions do not migrate into residential spaces. Type D homes require kitchen ventilation, cleaner service yards and generator setbacks. Type E institutional buildings require occupancy-based ventilation because crowding can rapidly raise CO₂ and odour, while Type F industrial and workshop buildings require source capture, buffer distances and exhaust-height control.

The Enugu office evidence reported by Basil et al. (2024) and educational facilities recorded by Mba et al., (2024) is particularly important because it shows that architectural features can explain a large proportion of indoor air-quality variation in local buildings. That finding supports the broader conceptual claim of this article: building design is not a marginal issue in air-pollution control. It is a practical and measurable part of the exposure chain. Similar Nigerian findings on residential particulate matter and school indoor environmental quality also support the need for typology-sensitive interventions (Jelili et al., 2020; Toyinbo et al., 2019).

5.3 Green infrastructure must be designed, not merely added

Green infrastructure should be used carefully. The reviewed evidence suggests that vegetation can reduce particulate exposure by deposition and barrier effects, but it may also obstruct ventilation in narrow canyons if dense canopies are placed without considering street geometry and prevailing wind (Abhijith et al., 2017; Diener & Mudu, 2021; Kumar et al., 2024). For Enugu, this means that hedges, vegetated setbacks, green walls and courtyard planting may often be more appropriate than continuous dense tree canopies in very narrow streets. Larger trees remain valuable for shade, heat reduction and comfort, but their placement must allow airflow rather than forming a pollutant-trapping roof over busy roads.

Blue-green features such as planted courtyards, permeable paving, vegetated drains, rain gardens and shaded open spaces can also reduce dust resuspension and heat-island intensity. However, open water should not be recommended indiscriminately as a pollution solution. Poorly maintained water features may become mosquito-breeding or humidity problems. In a journal-ready design framework, the stronger recommendation is not that wealthy clients should add swimming pools, but that all projects should integrate maintainable green-blue infrastructure appropriate to site size, climate, budget and public-health risk.

5.4 Methodological and regulatory implications

The method used in this article is conceptual, so its findings should be read as a framework for design and future research rather than as measured pollutant concentrations. Future empirical work can test the framework by monitoring PM_{2.5}, PM₁₀, CO, CO₂, NO₂, TVOCs, temperature and humidity across the six typologies during rainy and dry seasons. Sampling should compare indoor and outdoor locations, distance from roads and generators, opening types, filter ratings, occupancy and landscape characteristics. This would allow the conceptual risk scores in Figure 3 to be replaced or calibrated with measured values. Regulatory implications are immediate. Nigerian building-control review tends to focus on plot coverage, structural safety, fire access and planning conformity, while indoor air quality

and site-level pollutant exposure receive limited explicit attention. A practical air-quality review checklist can be added to building approval without requiring costly technology. This checklist should examine generator location, exhaust height, waste storage, road-facing openings, fresh-air intake location, ventilation routes, material specification, dust-control measures, construction logistics, planting strategy and post-construction verification.

5.5 Contribution to sustainable architecture

The article contributes to sustainable architecture by connecting environmental health with everyday design decisions. Sustainable design is often framed as energy efficiency or carbon reduction, but a building that saves energy while trapping pollutants or recirculating contaminated air cannot be considered sustainable (Frontczak & Wargocki, 2011; Seppanen & Fisk, 2006). Conversely, a building that uses passive cooling, controlled ventilation, low-emission materials and well-designed landscape can reduce both operational energy and exposure. This dual focus aligns with healthy-building research, which links ventilation, materials and occupant well-being with productivity and health outcomes (Allen et al., 2016; Fisk, 2000)

6 Conclusions

Architecture is an active mediator of air-pollution exposure because design decisions influence emissions, heat, pollutant dispersion, infiltration, indoor accumulation and human exposure. This review identifies seven interrelated architectural pathways: urban form and site planning; envelope and orientation; ventilation and filtration; materials and finishes; building operation; construction activity; and landscape and drainage. In the Enugu context, generator dependence, road-facing commercial frontages, poorly located air intakes, high-emission finishes, construction dust, weak waste management and inadequate landscape buffering intensify these pathways. The micro-macro framework further demonstrates that repeated plot-level design decisions can accumulate into neighbourhood- and city-scale air-quality effects, while the typological analysis indicates that street-front commercial and industrial/workshop buildings require particularly strong design attention because of their proximity to active pollution sources and limited source separation. These findings have direct implications for architectural practice, planning and building-control review. Air-quality considerations should be incorporated into site-plan approval through checks on generator location and exhaust height, waste storage, service yards, road-facing openings, fresh-air intake positions, ventilation routes, material specification, construction-dust control and landscape design. Design teams should prioritise passive cooling, context-sensitive green-blue infrastructure, low-emission materials, protected ventilation openings and post-construction indoor-air-quality checks. These measures provide practical opportunities to reduce occupant exposure while also limiting cooling demand and dependence on fossil-fuelled generators.

The study is limited by its qualitative, evidence-informed design. It does not present primary air-quality monitoring, a statistically representative survey of Enugu buildings, atmospheric modelling or measured pollutant concentrations. The proposed building typologies and relative exposure categories should therefore be interpreted as conceptual design-prioritisation tools rather than measured risk estimates. Consequently, the recommendations require empirical validation before they are treated as quantified performance standards or universally applicable design prescriptions.

Future research should test the framework through comparative monitoring across the six proposed building typologies during both rainy and dry seasons, using indoor and outdoor

measurements of PM_{2.5}, PM₁₀, CO, CO₂, NO₂, TVOCs, formaldehyde, temperature and relative humidity. Such studies should examine distance from roads and generators, opening types, ventilation and filtration performance, occupancy and landscape characteristics, and should evaluate whether the recommended design interventions produce measurable reductions in exposure. A subsequent systematic review using a PRISMA-based protocol would further strengthen the evidence base and support the development of an air-quality checklist for architectural approval in Enugu and comparable tropical African cities.

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Data Availability Statement

The dataset analyzed during the study is available from the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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