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Factors affecting indoor air quality (IAQ), common indoor pollutants, measurement systems, and standards. Outdoor air quality (OAQ): common sources of pollution in cities and rural areas, monitoring methods, and current EU and national laws

Examples of best practices: sensors, and integrated systems for tracking air quality, design concepts for air quality management systems.

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Erasmus+ KA220 Cooperation Partnerships in Higher Education
Increasing the Visibility and Knowledge Base on Air Quality With Big Data and Its Impact on the Population Health
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Why Air Quality Matters



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INDOOR AIR QUALITY (IAQ): THE CONFINED ENVIRONMENT

Defining IAQ

Quality of the air within and around buildings and structures, especially as it relates to the health and comfort of building occupants.

The Assessment of IAQ

Involves the measurement and analysis of thermal conditions (temperature, humidity) and the concentration of a wide variety of airborne pollutants, including chemical, physical, and biological contaminants.

INDOOR AIR QUALITY (IAQ): THE CONFINED ENVIRONMENT

Adverse Health Outcomes

Poor IAQ has been irrefutably linked to a range of adverse health outcomes, from short-term issues like irritation of the eyes, nose, and throat, headaches, and fatigue, to long-term chronic conditions such as asthma, cardiovascular disease, and cancer.

Critical Factors Influencing IAQ

The quality of air within a building is not static; it is a **dynamic system** influenced by a continuous interplay of several key factors.



Critical Factors Influencing IAQ

Ventilation and Air Exchange Rate

Ventilation is the process of exchanging indoor air with outdoor air to dilute and remove airborne pollutants originating from indoor sources. The rate at which this occurs, known as the Air Exchange Rate (AER), is a primary determinant of IAQ.

- **Low Ventilation:** In an effort to improve energy efficiency, *modern buildings* are often constructed to be more airtight. While this reduces heating and cooling costs, it can also lead to insufficient ventilation, causing pollutants to accumulate to hazardous levels.
- **Natural vs. Mechanical Ventilation:** Ventilation can be natural (e.g., opening windows and doors), mechanical (e.g., HVAC systems), or a hybrid of both. The effectiveness of natural ventilation is highly dependent on occupant behavior and external weather conditions, while mechanical systems offer more consistent but energy-intensive control.

Critical Factors Influencing IAQ

Building Characteristics and Materials

- **Building Age and Materials:** Older buildings may contain hazardous materials like asbestos or lead-based paint. Newer buildings, however, can be sources of a wide range of Volatile Organic Compounds (VOCs) emitted from new carpets, furniture, paints, and composite wood products.
- **Dampness and Mold:** The presence of moisture due to leaks, condensation, or high humidity can promote the growth of mold and bacteria, which release spores and microbial VOCs into the air, posing a significant health risk.

Critical Factors Influencing IAQ

Occupant Behavior and Activities

- **Respiration:** Humans exhale Carbon Dioxide (CO_2), and high concentrations of CO_2 are a direct indicator of inadequate ventilation relative to occupant density.
- **Cooking and Heating:** Combustion processes, especially from gas stoves or biomass-burning fireplaces, release significant quantities of Particulate Matter (PM), Carbon Monoxide (CO), and Nitrogen Oxides (NO_x).
- **Consumer Products:** The use of cleaning agents, air fresheners, personal care products, and hobby materials can release a complex mixture of chemicals into the indoor air.
- **Environmental Tobacco Smoke (ETS):** Smoking indoors is a major source of thousands of toxic chemicals and carcinogens.

Critical Factors Influencing IAQ

The Infiltration of Outdoor Air

The relationship between indoor and outdoor air is **bidirectional**. Outdoor pollutants can penetrate buildings through ventilation systems, cracks, and other openings in the building envelope. In urban areas, this means that traffic-related pollutants like $PM_{2.5}$ and NO_x can become significant indoor pollutants.

Studies have shown that indoor PM concentrations can be 1.25 to 12.67 times higher than their outdoor counterparts, indicating the powerful influence of both infiltration and strong indoor sources.

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Common Indoor Pollutants: Sources and Health Effects

The indoor environment is a complex chemical soup containing hundreds of potential pollutants.



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Common Indoor Pollutants: Sources and Health Effects

Particulate Matter ($PM_{2.5}$ & PM_{10})

Is a mixture of solid particles and liquid droplets suspended in the air. It is categorized by its aerodynamic diameter.

- *PM_{10} (Coarse Particles):* Diameter of 10 µm or less. They can be inhaled and deposited in the upper respiratory tract. Sources include dust, pollen, and mold.
- *$PM_{2.5}$ (Fine Particles):* Diameter of 2.5 µm or less. These are of greatest concern as they can penetrate deep into the lungs and even enter the bloodstream.

Sources: Indoor sources include cooking (especially frying), burning candles, smoking, and resuspension of dust. Outdoor sources that infiltrate indoors include traffic emissions, industrial processes, and construction.

Health Effects: Short-term exposure can trigger asthma attacks and worsen respiratory conditions. Long-term exposure is linked to cardiovascular disease, respiratory illnesses, and lung cancer.

Common Indoor Pollutants: Sources and Health Effects

Gaseous Pollutants

Volatile Organic Compounds (VOCs)

Large group of carbon-based chemicals that easily evaporate at room temperature.

- *Formaldehyde:* A common and hazardous VOC found in pressed-wood products (particleboard, MDF), glues, and some insulation materials. It is a known human carcinogen.
- *Benzene:* Found in tobacco smoke, stored fuels, and paint supplies. It is also a known human carcinogen, linked to leukemia.
- *Other VOCs:* A vast array of other VOCs are emitted from paints, cleaning supplies, pesticides, and office equipment like printers.

Health Effects: Effects range from eye and respiratory tract irritation, headaches, and dizziness to severe long-term effects like liver damage and cancer.

Common Indoor Pollutants: Sources and Health Effects

Gaseous Pollutants

Combustion Gases (CO, NO_2, SO_2)

Produced by burning fuels.

- *Carbon Monoxide (CO):* A colorless, odorless gas produced by incomplete combustion. Sources include faulty furnaces, gas stoves, and attached garages. CO is highly toxic, interfering with oxygen transport in the blood, and can be fatal at high concentrations.
- *Nitrogen Dioxide (NO_2):* A reddish-brown gas produced by high-temperature combustion. Major indoor sources are unvented gas stoves and heaters. It can irritate the respiratory system and increase susceptibility to infections.
- *Sulphur Dioxide (SO_2):* Primarily an outdoor pollutant from industrial sources that can infiltrate indoors. It can cause breathing difficulties, especially for people with asthma.

Common Indoor Pollutants: Sources and Health Effects

Gaseous Pollutants

Carbon Dioxide (CO_2)

Source: Primarily from human respiration.

While not typically considered toxic at levels found in most buildings, CO_2 is an excellent indicator of ventilation effectiveness.

High levels (e.g., >1000 ppm) are associated with occupant complaints of drowsiness, headaches, and poor concentration.

Common Indoor Pollutants: Sources and Health Effects

Biological Pollutants

Includes all airborne pollutants of biological origin.

Sources: Mold, bacteria, viruses, dust mites, animal dander, and pollen. They thrive in damp or humid environments.

Health Effects: Can trigger allergic reactions, asthma, and other respiratory illnesses. Some molds produce mycotoxins that can have more severe health effects.

Common Indoor Pollutants: Sources and Health Effects

Radon and Other Specific Pollutants

- *Radon:* A naturally occurring radioactive gas that can seep into buildings from the soil and rock beneath. It is colorless and odorless and is the second leading cause of lung cancer.
- *Asbestos:* A mineral fiber previously used in insulation and other building materials. If disturbed, its fibers can become airborne and, when inhaled, can cause lung cancer and mesothelioma.
- *Lead:* Can be found in dust from deteriorating lead-based paint in older homes or from contaminated soil tracked indoors. It is a potent neurotoxin, particularly harmful to children.

Measurement Systems and Prevailing Standards

The regulation of IAQ is significantly less cohesive than that for outdoor air. There is a patchwork of **guidelines and standards** from various international and national bodies rather than a single, overarching legislative framework.

Measurement Systems and Prevailing Standards

Global Guidance: The World Health Organization (WHO)

The WHO provides authoritative, health-based guidance.

- WHO Air Quality Guidelines (AQGs): While primarily focused on ambient air, these guidelines for pollutants like PM, NO_2, and SO2 are often referenced for indoor environments.
- WHO Guidelines for Indoor Air Quality: The WHO has also published specific guidelines for indoor environments, such as the 2010 report on "Selected Pollutants," which established guideline values for substances like formaldehyde, carbon monoxide, radon, and benzene.

Measurement Systems and Prevailing Standards

Occupational and Engineering Standards (ASHRAE, OSHA)

- American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE): ASHRAE standards (e.g., ASHRAE 62.1 and 62.2) are highly influential globally. They focus on providing acceptable IAQ through ventilation by specifying minimum ventilation rates for different types of buildings.
- Occupational Safety and Health Administration (OSHA): OSHA sets permissible exposure limits (PELs) for a wide range of chemicals in the workplace to protect workers' health. These are legally enforceable standards but are specific to occupational settings.

Measurement Systems and Prevailing Standards

The European Context and Regulatory Gaps

At the European Union level, the situation is complex. While numerous policies target outdoor air pollution, a unified strategy for IAQ is notably absent. This has led scholars to describe IAQ as a "*regulatory no [wo] man's land*".

SCHER's Role: The European Commission's Scientific Committee on Health and Environmental Risks (SCHER) plays an advisory role, identifying indoor pollutants of concern and recommending the development of health-based guideline values. SCHER has highlighted pollutants like formaldehyde, benzene, CO, and NO_x as priorities.

Lack of Binding Legislation: Despite this advisory work, there are no binding, EU-wide limit values for indoor air pollutants in non-occupational settings. Regulation is largely left to individual member states, resulting in a fragmented and inconsistent approach across the continent.

OUTDOOR AIR QUALITY (OAQ): THE AMBIENT ENVIRONMENT

Defining IAQ

Condition of the air in the ambient (outdoor) atmosphere.

It is a critical determinant of public health and environmental well-being.

Poor OAQ results from the emission of harmful gases and particulate matter from both natural and anthropogenic (human-caused) sources.

Principal Sources of Outdoor Pollution



Principal Sources of Outdoor Pollution



Principal Sources of Outdoor Pollution

Urban Pollution Sources

Cities are hotspots for air pollution due to high population density and economic activity.

- **Mobile Sources:** This is the dominant category in most urban areas. It includes all forms of transport: cars, trucks, buses, and aircraft. The combustion of fossil fuels in these vehicles releases $PM_{2.5}$, Nitrogen Oxides NO_x, which contribute to the formation of ozone), Carbon Monoxide (CO), and VOCs.

Principal Sources of Outdoor Pollution

Urban Pollution Sources

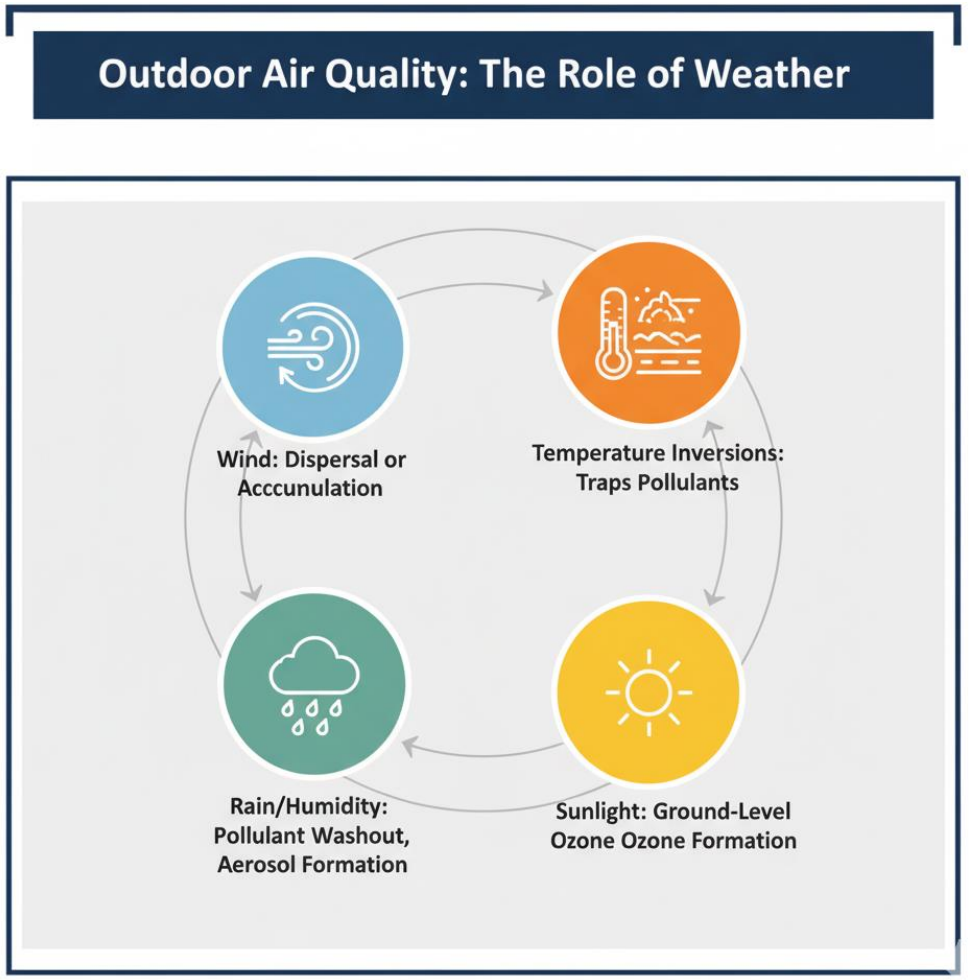
- **Stationary Sources:**
  - *Industrial Point Sources:* Include power plants, factories, and refineries, which can emit large quantities of SO_2, NO_x, PM, and heavy metals.
  - *Area Sources:* A collection of smaller sources, such as residential and commercial heating, and municipal waste incineration.
  - *Fugitive Sources:* Dust from construction sites, paved and unpaved roads, and other activities that becomes airborne.

Principal Sources of Outdoor Pollution

Rural Pollution Sources

- *Agriculture:* This is a primary source, with activities like livestock farming releasing ammonia and methane. The use of fertilizers can also contribute to nitrogen pollution, and dust from tilling fields adds to particulate matter.
- *Biomass Burning:* The burning of wood for residential heating and the burning of agricultural waste are major sources of PM and Polycyclic Aromatic Hydrocarbons (PAHs).
- *Mining and Quarrying:* These activities can release large amounts of particulate matter into the atmosphere.

The Role of Weather



Methodologies for Monitoring OAQ

The management of OAQ relies on accurate assessment and monitoring. The standard approach involves a network of fixed-site monitoring stations.

- **Reference Monitors:** These stations use highly accurate, standardized methods to continuously measure the concentration of key pollutants (e.g., $PM_{2.5}$, PM_{10}, O_3, NO_2, SO_2, CO).
- **Standardization:** International bodies like the International Organization for Standardization (ISO) provide technical standards for monitoring methods to ensure data are comparable and reliable across different locations and countries.
- **Limitations:** While essential, fixed-site networks can be sparse, providing an incomplete picture of air quality variations within a city, particularly regarding personal exposure.

Regulatory Frameworks: EU & National Legislation

In contrast to IAQ, OAQ is subject to **extensive and legally binding regulation** in many parts of the world.

- WHO Foundation: The WHO's global Air Quality Guidelines (AQGs) provide the scientific foundation upon which many countries build their national standards. These are not legally binding in themselves but represent the benchmark for protecting public health.

Regulatory Frameworks: EU & National Legislation

- EU Legislation: The European Union has a comprehensive body of legislation aimed at controlling outdoor air pollution. The core of this is the **Ambient Air Quality Directive (2008/50/EC)**. This directive sets legally binding limit values and target values for major air pollutants that member states must not exceed. It also mandates that member states monitor air quality and develop air quality plans for zones where limits are breached.
- National Laws: Individual member states translate these EU directives into national law and are responsible for their implementation and enforcement. This creates a relatively harmonized and robust regulatory system for outdoor air quality across the EU.

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BEST PRACTICES IN AIR QUALITY MANAGEMENT AND TECHNOLOGY

The *growing awareness of air quality's impact* on health has spurred significant innovation in monitoring and management technologies.

The Rise of Advanced Sensor Technologies

A major shift in air quality monitoring is the move towards *more distributed and accessible sensing*.

The Rise of Advanced Sensor Technologies

Low-Cost Sensor Networks

- **Functionality:** These sensors can measure key pollutants like PM, VOCs, and CO_2. Devices like the *Plantower PMS5003* for particulate matter have become common in both consumer and research applications.
- **Advantages:** Their low cost allows for deployment in dense networks, providing high-resolution spatial and temporal data that fixed-site monitors cannot capture. This is invaluable for identifying pollution hotspots and understanding personal exposure.
- **Challenges:** The accuracy and reliability of low-cost sensors can vary. Best practices involve careful calibration against reference instruments and robust data validation protocols.

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The Rise of Advanced Sensor Technologies

Technological Innovations (MEMS)

Disruptive innovations are further enhancing sensor capabilities.

- **Ultrasonic MEMS (Micro-Electro-Mechanical Systems) Sensors:** This emerging technology offers the potential for highly accurate and affordable sensors. By using micro-scale ultrasonic transducers, they can detect particles and gases with high sensitivity, bridging the gap between low-cost sensors and expensive reference instruments.

Integrated Systems for Comprehensive Air Quality Tracking

Multi-Sensing Platforms and AI Integration

Best practices now involve *combining data from multiple sources.*

- **Multi-Sensing Platforms:** These platforms integrate data streams from various types of sensors (e.g., IAQ sensors, thermal comfort sensors, occupancy counters) to create a holistic picture of the indoor environment.
- **Artificial Intelligence (AI):** AI algorithms are increasingly used to analyze these large, complex datasets. AI can help validate sensor data, identify pollution sources, predict air quality events, and optimize building controls in real time.

Integrated Systems for Comprehensive Air Quality Tracking

EU Research Initiatives

The European Union is actively funding research to advance these technologies.

The IDEAL Cluster, for example, comprises seven research projects (including K-HEALTHinAIR, InChildHealth, etc.) focused on IAQ.

Key principles:

- Developing advanced monitoring systems and novel sensors.
- Conducting health impact assessments using real-life data, especially for vulnerable groups like children.
- Creating solution-oriented interventions that have practical applications.

Advanced Design Concepts for Air Quality Management

Effective management is not just about *monitoring*; it is also about proactive *design and control*.

Smart Ventilation & Control Systems

The core design concept is to link real-time monitoring to automated building controls.

- **Demand-Controlled Ventilation (DCV):** Instead of ventilating at a constant rate, DCV systems use sensors (e.g., CO_2 or occupancy sensors) to adjust the ventilation rate based on the actual demand. This ensures good IAQ when the building is occupied while saving significant energy when it is not.
- **Integrated Control:** Smart systems can make intelligent decisions, such as increasing ventilation in response to a detected rise in VOCs or temporarily reducing outdoor air intake during a peak outdoor pollution event.

Advanced Design Concepts for Air Quality Management

The Role of Natural Ventilation

While mechanical systems offer control, natural ventilation remains a key strategy for improving IAQ and reducing energy consumption.

- **Hybrid Systems:** Best-practice designs often incorporate hybrid ventilation systems that utilize natural ventilation when outdoor conditions are favorable (e.g., mild temperature, low pollution) and switch to mechanical ventilation when necessary.
- **Smart Facades:** Advanced building facades with automated windows and vents can be controlled by the building management system to optimize natural airflow.

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Advanced Design Concepts for Air Quality Management

Holistic Building Design for Health and Efficiency

The most advanced approach considers the building as an integrated system.

This involves a design process that balances IAQ, thermal comfort, lighting, and energy efficiency from the outset.

This includes careful material selection to minimize VOC emissions, building orientation to optimize natural light and ventilation, and the integration of smart controls to ensure the building operates in a healthy and efficient manner throughout its lifecycle.

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CONCLUSIONS

Key Findings

- **Indoor** environments often contain **higher pollutant** concentrations than outdoors. This is due to indoor sources, building characteristics, and infiltration of outdoor contaminants.
- While outdoor air is regulated (e.g., in the EU), **indoor** air quality (IAQ) is mostly addressed through **non-binding guidelines**.
- **Technology is advancing rapidly:** Sensors and AI-driven systems offer new tools for air monitoring and management.

CONCLUSIONS

The Interconnectedness of IAQ & OAQ

- There is an **undeniable link** between indoor and outdoor air quality.
- Effective IAQ strategies must consider the **quality of intake air**.
- **Urban planning and traffic policies** that improve outdoor air will also **benefit indoor** environments.
- A **holistic public health strategy** must address **pollution sources both** inside and outside buildings.

CONCLUSIONS

Future Directions & Research Needs

Knowledge gaps remain despite progress.

Key research priorities:

- **Combined Effects:** Long-term exposure to complex mixtures of low-concentration indoor pollutants.
- **Vulnerable Populations:** Risks to children, the elderly, and those with pre-existing conditions.
- **Standardization:** Development of harmonized, health-based IAQ standards and binding regulations, especially in the EU.
- **Technology Validation:** Standardizing low-cost sensor performance to improve reliability and regulatory acceptance.

Addressing these challenges is essential to fulfill the two-decade-old promise of the **"right to healthy indoor air".**

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