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The Effects of Climate Change on Indoor Air Quality: New Strategies for Healthier Environments

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Abstract

This research investigates the influence of climate change on indoor environments, with a primary focus on indoor air quality (IAQ). It underscores how rising global temperatures, shifting humidity levels, and the escalation of extreme weather events are deteriorating IAQ, presenting significant health risks. Major concerns addressed include the heightened infiltration of outdoor pollutants, elevated indoor temperatures, and increased mold growth linked to rising humidity. The study underscores the urgent need to improve building designs and ventilation systems to counter these issues effectively. Ultimately, it concludes that swift, proactive measures are essential to safeguard human health against the adverse impacts of climate change on indoor living spaces.

Keywords

Climate change, Indoor air quality (IAQ), Ventilation, Mold growth, Pollutants, Building design.

1. Introduction

Climate change is rapidly altering not just outdoor environments, but also the quality of indoor air, which is critical to human health. As global temperatures rise and extreme weather events become more frequent, indoor air quality (IAQ) faces increasing threats. In modern societies, where people spend the majority of their time indoors, maintaining good IAQ is essential. Poor IAQ can lead to numerous health problems, including respiratory issues, allergies, and cardiovascular diseases, making it a crucial factor in overall well-being.

Rising temperatures are among the most immediate outcomes of climate change, profoundly impacting indoor environments. Warmer indoor air can accelerate the release of volatile organic compounds (VOCs) from materials like paint, flooring, and insulation, which diminishes air quality and triggers health symptoms such as headaches, dizziness, and respiratory irritation. Additionally, the increase in humidity that accompanies higher global temperatures fosters conditions ripe for mold growth, exacerbating indoor air quality (IAQ) issues. Mold spores and microbial volatile organic compounds (MVOCs) present serious health risks, particularly for individuals with pre-existing respiratory conditions, compounding the urgency for strategies to counter these indoor pollutants.

Moreover, climate change is increasing the frequency of extreme weather events such as wildfires, dust storms, and storms, all of which contribute to higher levels of outdoor air pollution. Pollutants like particulate matter (PM2.5) and ozone can infiltrate indoor spaces, worsening IAQ and endangering human health, particularly for vulnerable groups like children, the elderly, and those with pre-existing health conditions.

This paper examines how climate change is worsening IAQ and explores strategies for mitigating these impacts through improved building design, enhanced ventilation systems, and updated IAQ standards. As climate change accelerates, the need to protect indoor environments from its effects becomes increasingly urgent.

2. Temperature and Humidity Changes

2.1. Temperature Increases

One of the most immediate and perceptible consequences of climate change is the rise in average global temperatures, which significantly impacts not only outdoor but also indoor environments. In buildings with insufficient insulation or inadequate air conditioning systems, these higher temperatures can lead to uncomfortable and even unsafe indoor conditions. This lack of thermal regulation exacerbates indoor thermal stress, affecting the comfort, well-being, and productivity of occupants. Such environments can lead to physical discomfort, reduced focus, and higher stress levels, highlighting the critical need for improved building designs that adapt to these evolving climate challenges.

Increased indoor temperatures also accelerate the release of certain pollutants, such as volatile organic compounds (VOCs), from building materials, furnishings, and cleaning products. VOCs are chemical compounds that easily become vapors or gases at room temperature. They are emitted by a wide range of products, including paints, carpets, and building materials. As temperatures rise, these substances off-gas more readily, leading to a significant degradation in indoor air quality. Prolonged exposure to high levels of VOCs can cause respiratory issues, headaches, dizziness, and other health problems. In poorly ventilated indoor environments, such pollutants can accumulate, posing long-term risks to occupants.

2.2. Humidity Changes

In addition to temperature increases, climate change also affects indoor humidity levels, particularly in regions prone to heavy rainfall or flooding. The relationship between temperature and humidity is crucial because warmer air can hold more moisture. As outdoor temperatures rise, indoor spaces, especially those with poor ventilation, often experience higher humidity levels.

High humidity creates an ideal environment for mold growth. Mold is a type of fungus that thrives in moist conditions, and it releases spores into the air, which can trigger allergic reactions and respiratory problems in individuals exposed to it. Mold growth is particularly concerning in regions with frequent flooding or water damage. As global temperatures rise and precipitation patterns change, these areas are likely to experience more frequent mold infestations. In severe cases, mold exposure can lead to asthma attacks and other chronic respiratory conditions.

The relationship between temperature and humidity is described by the following formula:

$$RH = \frac{e(T)}{e_s(T)} \times 100$$

Among them, RH is the relative humidity, $e(T)$ is the actual vapor pressure, and the saturated vapor pressure at a given temperature is $e_s(T)$.

This formula illustrates how an increase in temperature can result in a higher capacity for the air to hold moisture, leading to elevated relative humidity levels. In indoor environments where both temperature and humidity are elevated, the risk of mold growth increases significantly.

3. The Infiltration of Outdoor Pollutants

3.1. Pollutants from Wildfires and Extreme Weather

An indirect yet significant way climate change impacts indoor air quality is through the rise in extreme weather events that contribute to heightened outdoor air pollution. Events such as wildfires, dust storms, hurricanes, and floods have become increasingly frequent and severe in many regions due to climate change. These events release diverse pollutants, including fine particulate matter (PM2.5), ozone, and various harmful gases, which degrade outdoor air quality. These pollutants can easily infiltrate indoor spaces, particularly through ventilation systems, open windows, and even small gaps in the building envelope. During extreme weather conditions, when buildings are often more vulnerable to the elements, these pollutants can enter more readily, further compromising indoor air quality and posing health risks for occupants.

PM2.5, or particulate matter smaller than 2.5 micrometers in diameter, is particularly dangerous because it can penetrate deep into the lungs and even enter the bloodstream. Exposure to high levels of PM2.5 has been linked to respiratory and cardiovascular diseases, as well as premature death. During wildfire events, for example, PM2.5 levels can rise significantly, posing a serious health risk to individuals indoors if the building's ventilation system is not properly equipped to filter out these particles.

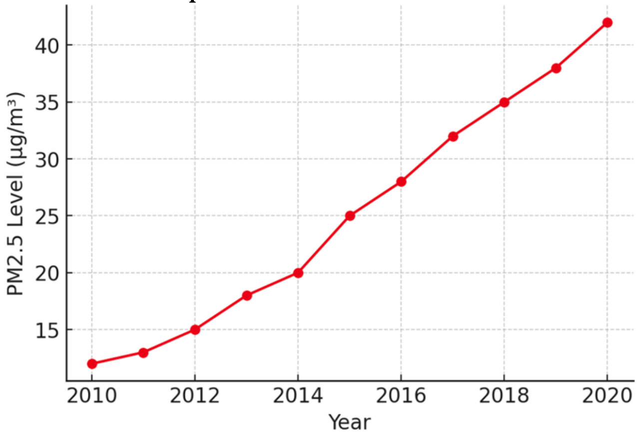

Fig.1 Annual PM2.5 levels caused by wildfires from 2010 to 2020.

3.2. The Role of Filtration Systems

To address the issue of outdoor pollutants infiltrating indoor environments, buildings need to be equipped with advanced filtration systems. Traditional ventilation systems that rely on natural airflow or basic filters are not sufficient to protect indoor air from pollutants such as PM2.5 and ozone. HEPA (High-Efficiency Particulate Air) filters are highly effective at capturing fine particles like PM2.5, removing them from the air before they can enter indoor spaces. These filters are capable of trapping 99.97% of particles that are 0.3 microns or larger, making them an essential tool in maintaining good indoor air quality during extreme pollution events.

To combat the influx of harmful pollutants indoors, carbon filters, alongside particulate filters, offer an effective solution for reducing gaseous contaminants such as volatile organic compounds (VOCs) and ozone. When combined, HEPA and carbon filters in ventilation systems create a comprehensive filtration approach, significantly lowering both particulate and gaseous pollutant levels in indoor spaces. Upgrading building filtration systems with this dual-filter setup is a vital step toward protecting indoor air quality, especially in areas increasingly affected by wildfires, dust storms, and extreme weather events exacerbated by climate change. This approach not only enhances air quality but also supports healthier indoor environments in the face of escalating outdoor pollution levels.

4. Ventilation and Energy Efficiency

4.1. Energy-Efficient Ventilation

Proper ventilation is essential for maintaining good indoor air quality. However, traditional ventilation systems that draw in large amounts of outdoor air may not be effective in areas with

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high levels of outdoor air pollution. In addition, these systems can be energy-intensive, particularly in regions where cooling or heating is required for much of the year. As climate change leads to more frequent heatwaves and extreme weather events, the demand for energy-efficient ventilation systems will only increase.

Heat Recovery Ventilation (HRV) systems present an energy-efficient solution for maintaining indoor air quality (IAQ) with minimal energy costs. These systems function by exchanging stale indoor air with fresh outdoor air while capturing and reusing heat energy from the outgoing exhaust air. This heat exchange process enables buildings to improve IAQ without the substantial energy costs typically associated with heating and cooling. In summer, HRV systems reduce the demand for air conditioning by pre-cooling incoming air, while in winter, they conserve heat by warming incoming air. Consequently, HRV systems contribute to lower overall energy consumption, supporting a comfortable and healthier indoor environment that aligns with energy-saving goals.

4.2. Improving Ventilation Design

In addition to using advanced filtration and energy-efficient technologies, the design of ventilation systems must be optimized to address the challenges posed by climate change. In regions where outdoor air quality is frequently compromised by wildfires, dust storms, or industrial pollution, buildings should be equipped with air intake systems that can automatically adjust based on outdoor air quality levels. When outdoor air quality is poor, ventilation systems should reduce the intake of outdoor air and rely more heavily on recirculating and filtering indoor air to maintain IAQ.

To further improve energy efficiency, ventilation systems can be integrated with building management systems (BMS) that monitor and control airflows based on real-time data about indoor and outdoor conditions. By adjusting ventilation rates in response to occupancy levels, indoor temperatures, and outdoor air quality, BMS-integrated systems can ensure optimal air quality while minimizing energy use.

5. Building Design Considerations

5.1. Materials for Climate Resilience

Building design is essential in preserving indoor air quality, especially as climate change intensifies extreme weather events and outdoor pollution. Climate-resilient design involves carefully selecting materials that can endure temperature swings, high humidity, and moisture exposure. In areas with heavy rainfall or frequent flooding, materials with mold- and moisture-resistant properties should be prioritized. For instance, using mold-resistant drywall and water-repellent paints can significantly lower the risk of mold development in moisture-prone buildings. By incorporating these durable materials, buildings can better withstand environmental stresses, promoting healthier indoor environments and long-term resilience against climate-driven challenges.

Improving insulation is another important aspect of climate-resilient building design. By using materials with high thermal resistance (R-values), buildings can reduce their reliance on energy-intensive heating and cooling systems. The following equation shows how heat transfer through building materials can be minimized:

$$Q = \frac{A \cdot U \cdot \Delta T}{R}$$

Among them, Q is the heat transfer rate is, U is the heat transfer coefficient, A is surface area, ΔT is temperature difference, and R is the thermal resistance of the material. The higher the R value, the better the insulation effect of the building.

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By using materials with higher R-values, buildings can become more energy-efficient and better insulated against extreme temperatures.

Table 1 Comparison of R-values for common building materials.

Material	R-value ($m^2 \cdot K/W$)
Fiberglass Insulation	3.7
Cellulose Insulation	3.6
Concrete Block	0.2
Wood Frame	1.4

5.2. Adapting to High Humidity Environments

In regions where climate change is expected to increase humidity levels or where heavy rainfall and flooding are frequent, building designs must prioritize moisture control. In such areas, building materials must be selected to minimize the risk of mold growth, and moisture barriers should be installed to prevent water from penetrating the building envelope. Additionally, mechanical dehumidification systems should be incorporated into the building's HVAC system to control indoor humidity levels and reduce the risk of mold growth and other moisture-related issues.

6. Impact on Vulnerable Populations

6.1. Health Risks for Vulnerable Groups

Climate change amplifies the health risks linked to poor indoor air quality, especially for vulnerable groups such as children, the elderly, and individuals with pre-existing conditions like asthma, chronic obstructive pulmonary disease (COPD), and cardiovascular issues. Children are particularly sensitive to air pollution because their respiratory systems are still developing, making them more vulnerable to pollutants and allergens. As climate change drives more frequent extreme heat events, wildfires, and flooding, these populations face an increased risk of respiratory ailments, heat-related illnesses, and other serious health problems. This underscores the urgent need for climate-adaptive indoor environments that prioritize air quality and thermal comfort to protect those most susceptible to these growing health challenges.

6.2. Climate Change and Health Infrastructure

Hospitals, nursing homes, schools, and other institutions that cater to vulnerable populations must take extra precautions to maintain good indoor air quality. This includes upgrading ventilation systems to HEPA filters, ensuring proper temperature control, and implementing IAQ monitoring systems. By maintaining high IAQ standards, these institutions can protect their occupants from the adverse health effects of climate change.

7. Conclusion

Climate change poses significant challenges for maintaining healthy indoor environments, particularly regarding indoor air quality. Rising temperatures, increased humidity, and outdoor pollutants are all contributing to worsening IAQ. New building designs and ventilation systems that prioritize energy efficiency and resilience against climate change are essential to mitigating these risks. Special attention must be given to vulnerable populations who are most at risk from poor indoor air quality. Immediate action is necessary to ensure that indoor environments remain safe and healthy in the face of a changing global climate.

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