Indoor Air Quality Improvement

Subjects: Environmental Sciences
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Poor indoor air quality is a consequence of air contamination with pollutants whose sources may be natural or anthropogenic. The diversity of air contaminants range from particulate materials (PMs), biological pollutants, and over 400 different organic and inorganic chemical compounds, whose concentrations depend on both internal and external factors. Because people spend most of their time inside, poor indoor air quality causes serious human health issues, resulting in significant economic losses. Nature-based solutions using microalgae systems that mimic the role played by microalgae in the oceans, providing oxygen and biofixing carbon dioxide from the atmosphere, may be installed in new and already existing buildings to improve indoor air quality in an energy-conserving manner while providing autonomy to the building.

Keywords: CO2 mitigation ; indoor air quality ; microalgae ; health impact mitigation ; nature-based solutions ; circular economy

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1. Introduction

Humans require air to breath and live, mainly via the supply of oxygen, O_2, for cellular respiration. This provides the energy to operate the cellular metabolism to move, think, and perform other activities. Considering an adult respiratory rate of 12 to 18 breaths/minute, which equates to inhaling about half a litre of air, a person breathes approximately 17 m^3 air/day [1]. Air quality and human health are intertwined, and air quality is widely recognized as being one of the most important causes of disease in the 21st century [2][3][4]. Each year, more than 5 million people die prematurely from diseases attributable to poor indoor air quality, which also contributes to high economic losses due to reduced worker productivity, increased health care costs, and other material losses [2]. Indoor air pollutants are diverse, ranging from particulate materials (PMs), biological pollutants, and over 400 different organic and inorganic chemical compounds, whose concentrations depend on both internal and external factors [5]. Any contaminants, either chemical and biological, can result in significant health problems, which may lead to temporary or even permanent incapacitation, and, in extreme cases, to death, especially of those more vulnerable, i.e., children and the elderly. In crowded closed spaces, such as classrooms, the accumulated CO_2 exhaled by humans may reach levels higher than 5000 ppm which, although not presenting a risk to health, may affect the cognitive performance of the room's occupants. Adequate ventilation procedures should be taken to avoid levels of CO_2 concentration in indoor air that may affect behaviour and health [6].

Air is also the media by which a person can be contaminated with several diseases (the airborne route of infection), including, for example, flu, tuberculosis, and now, the COVID-19 pandemic. In airborne diseases, such as COVID-19, the air is the medium by which viruses are transported and transmitted between people, in the form of aerosols and fine particles.

Although indoor air quality has received less attention than outdoor air pollution, in the presence of indoor sources, indoor contaminant concentrations are higher, and sometimes 10-fold higher than the respective outdoor air levels (e.g., formaldehyde, whose sources vary from furniture to cleaning agents). Other example of contaminant associated with poor indoor air quality is radon, which is linked to some types of cancer, tobacco smoke, and emissions of volatile organic compounds (VOCs) [7].

2. The problem

In contemporary urban lifestyles, on average, citizens spend over 90% of their time in closed environments: at their homes, on public transport, and in offices, classrooms, restaurants, shops, and theatres. The combination of the generally higher indoor concentration of certain pollutants, and the fraction of time spent inside results in the overall domination of indoor air pollution exposure and opportunities for air borne diseases transmission. As a result, indoor spaces must be ventilated, and indoor air must be treated to prevent infection. The ventilation of indoor spaces is a common procedure used in buildings to provide thermal comfort and high-quality indoor air. This is traditionally undertaken by recycling most of the indoor air to prevent an additional energy load in the heating or cooling of the atmospheric air from outdoors. By comparison, new strategies involve the elimination of recirculation and the intensification of filtration. Both processes entail a higher energy demand and, consequently, higher costs, at the financial and environmental levels. Thus, it is important to consider new alternatives to ensure healthy indoor air at a reduced cost and a high energy efficiency.

In highly polluted environments, such as the case of certain cities, the ventilation of indoor spaces may increase the need for high air flows for renovation, with a corresponding sharp increase in the energy consumption parcel for ventilation; however, there is no guarantee that safe indoor air would be provided. Furthermore, in highly polluted areas it can be difficult to achieve the clean air quality needed by people with respiratory problems, particularly in the most vulnerable groups, i.e., the elderly and children.

Thus, a problem persists: if the quality of atmospheric air is not sufficient to ventilate indoor environments, how can the problem of the accumulation of substances in indoor air be solved?

3. Possible solutions

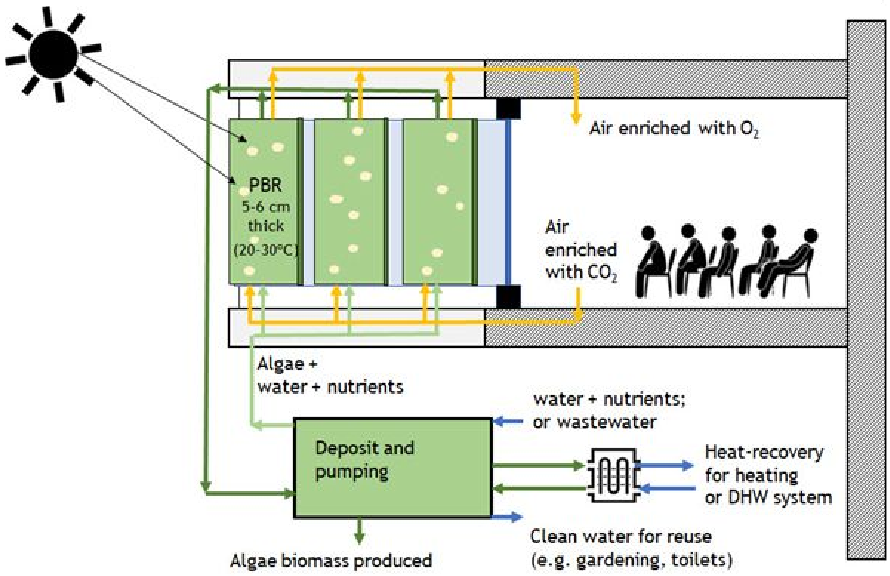
Several possibilities exist and have been implemented in practice. There are three strategies to promote good indoor air quality: source control, ventilation, and air cleaning or purification. Source control is the smartest strategy, because it avoids the problem at the source. However, in some cases, it is not able to be applied due to constraints related to construction materials or ongoing activities. Ventilation requires energy and implies emissions to the ambient air, at both the local and global scales. One of the emergent areas of indoor air quality is related to cleaning technologies. Various air treatment technologies can be used for control of contaminants. Conventional processes, such as sorption onto solid sorbents (for VOCs), filtration (for particulate matter, PM), and disinfection (for bioaerosols and microorganisms), are combined with advanced treatment processes, such as photocatalytic oxidation of VOCs, bipolar air ionization to agglomerate PM, and ultraviolet disinfection to inactivate bioaerosols [8]. Despite their high applicability, these processes have several disadvantages. For instance, for PM reduction, in the case of filtration, frequent replacement of filters is required and, in the case of electrostatic precipitation, a high risk of ozone generation exists. UV-photocatalytic oxidation appears to be a promising air cleaning technology. However, issues remain to be addressed before it can be used safely in buildings, such as generation of formaldehyde and acetaldehyde from partial oxidation of ubiquitous VOCs such as alcohols [9]. In addition, the high cost of these technologies and their accessibility by consumers need to be considered.

4. Nature-based solutions

Natural based solutions may be interesting alternatives. Biomimicry, theorized in 1997 by Janine Benyus [10], is an area of research that draws on existing solutions in nature to respond to human needs. This approach has been used in architecture to build more energy-efficient buildings and to improve their autonomy, therefore reducing the environmental footprint on the urban metabolism.

Another innovative and promising possibility is the creation of buildings, and potentially cities, that are powered by microalgae. This approach would contribute to the development of more environmentally friendly and sustainable cities with greater biodiversity. This article aims to highlight the potential of using microalgae to clean indoor air, and particularly to recycle dirty indoor air in buildings, based on the circular economy concept of reducing the use of resources and maximizing their benefits. The solution of integrating microalgae production systems in buildings potentially enables the quality of the indoor air to be better than that of atmospheric air. Simultaneously, this kind of solutions allows thermal regulation and new architectural features.

In the system here proposed (shown in the Figure), exhaust air from rooms or other building spaces, such as classrooms, is directly injected into the microalgae production system with several cultivation photobioreactors (PBR), providing a CO_2 source for the microalgae cultures. In each PBR, microalgae convert CO_2 into O_2 during their photosynthetic and metabolic activities, producing microalgae biomass. Rich O_2 air leaving the microalgae production system is connected to air handling systems (AHS), rather than (or complementing) outdoor atmospheric air, to be filtered and corrected for temperature and humidity levels, and then admitted, via a duct, into the rooms for ventilation purposes using and transforming the current Heating, Ventilating, and Air Conditioning (HVAC) system.



Microalgae cultivation system integrated into a building as the proposed solution for indoor air treatment, showing the air flow in and out of a room (authors' own creation).

Cities and buildings require combined and diversified efforts to design tailored solutions that are suitable for their specific needs. Microalgae "living labs" are expected to provide important knowledge regarding the responses of cities and the specific solutions to address the challenges of climate change. It can be hypothesized that buildings equipped with microalgae systems may improve positive social, environmental, and economic impacts. A microalgae PBR system is a promising alternative for improving the quality of indoor air. However, for practical and economic reasons, the design of the PBR system must be economically viable, particularly when compared with existing indoor air purifications systems. Such a comparison must consider the ease of maintenance, cleaning, and operation. In addition, the PBR system must be built with lightweight and durable materials to enable it to withstand the external environment. Furthermore, the optimal microalgae species or consortia still need to be specified, according to the local climatic and application-specific conditions. These aspects should be addressed in future R&D programs and projects, to further highlight the potential of microalgae-based systems for indoor air purification.

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