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Review

Can commonly-used fan-driven air cleaning technologies improve indoor air quality? A literature review

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ABSTRACT

Air cleaning techniques have been applied worldwide with the goal of improving indoor air quality. The effectiveness of applying these techniques varies widely, and pollutant removal efficiency is usually determined in controlled laboratory environments which may not be realized in practice. Some air cleaners are largely ineffective, and some produce harmful by-products. To summarize what is known regarding the effectiveness of fan-driven air cleaning technologies, a state-of-the-art review of the scientific literature was undertaken by a multidisciplinary panel of experts from Europe, North America, and Asia with expertise in air cleaning, aerosol science, medicine, chemistry and ventilation. The effects on health were not examined. Over 26,000 articles were identified in major literature databases; 400 were selected as being relevant based on their titles and abstracts by the first two authors, who further reduced the number of articles to 160 based on the full texts. These articles were reviewed by the panel using predefined inclusion criteria during their first meeting. Additions were also made by the panel. Of these, 133 articles were finally selected for detailed review. Each article was assessed independently by two members of the panel and then judged by the entire panel during a consensus meeting. During this process 59 articles were deemed conclusive and their results were used for final reporting at their second meeting. The conclusions are that: (1) None of the reviewed technologies was able to effectively remove all indoor pollutants and many were found to generate undesirable by-products during operation. (2) Particle filtration and sorption of gaseous pollutants were among the most effective air cleaning technologies, but there is insufficient information regarding long-term performance and proper maintenance. (3) The existing data make it difficult to extract information such as Clean Air Delivery Rate (CADR), which represents a common benchmark for comparing the performance of different air cleaning technologies. (4) To compare and select suitable indoor air cleaning devices, a labeling system accounting for characteristics such as CADR, energy consumption, volume, harmful by-products, and life span is

Abbreviations: AC, activated carbon; BTEX, benzene, toluene, ethyl benzene, and xylene; CADR, clean air delivery rate; CFM, cubic feet per minute; DBD, dielectric barrier discharge; EPA, Environmental Protection Agency; ESP, electrostatic precipitator; IAQ, indoor air quality; HEPA, high efficiency particulate air; PCO, photocatalytic oxidation; TCO, thermal catalytic oxidation; VOC, volatile organic compound; SOA, secondary organic aerosol; SP, submicron particles; SVOC, semi-volatile organic compound; TVOC, total volatile organic compound; UV-C, ultraviolet C, wavelength range: 280–100 nm; UVGI, ultraviolet germicidal irradiation; WHO, World Health Organization.

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necessary. For that purpose, a standard test room and condition should be built and studied. (5) Although there is evidence that some air cleaning technologies improve indoor air quality, further research is needed before any of them can be confidently recommended for use in indoor environments.

1. Introduction

Because indoor air quality is an important determinant of human health, comfort and productivity, high quality indoor air is desirable. Air cleaning technologies are of increasing importance, especially when building ventilation rates are being reduced to conserve energy. Numerous air cleaning technologies have been developed and used, but there have been no systematic assessments of these technologies. This is particularly true with regard to (1) application at realistic indoor conditions, (2) long-term performance, and (3) production of unwanted by-products during operation. The lack of widespread acceptance of reliable protocols for estimating the effectiveness of air cleaning systems has made it difficult to develop a standardized labeling system for indoor air cleaners, including standard methods for estimating Clean Air Delivery Rate (CADR). Consequently, a literature review was undertaken to collect state-of-the-art information on air cleaning technologies focusing on both their effects at removing indoor air pollutants and the problems that may occur during their application.

2. Methods

The scientific peer-reviewed literature on the effects of commonly-used gas-phase and particle phase air cleaners on indoor air pollutants in non-industrial indoor environments was reviewed by a multidisciplinary group of scientists with expertise in medicine, epidemiology, toxicology and engineering. The focus was only on air cleaning techniques for which indoor air flows through a device and is returned to the indoor environment ("fan-driven" air cleaners). Technologies like "catalyst in paint" or other passive air purification materials, masks and other personal protective devices were not included. Botanic air cleaners that did not involve flow-through systems were also excluded. Air cleaning devices that are intended only for outdoor air intakes (e.g., filters in mechanical ventilation system) were not considered. Consequently the air cleaners reviewed included only: high efficiency particulate air (HEPA), adsorption, ultraviolet germicidal irradiation (UVGI), photocatalytic oxidation (PCO), thermal catalytic oxidation (TCO), plasma, botanic air cleaners, ion generators, and electrostatic precipitators.

The selected air cleaning technologies were reviewed regarding their efficiency to reduce/remove indoor air pollutants including particles, microorganisms, inorganic and organic gases; radon was not included. The effects on health and/or occupant performance were not considered. For example, we did not consider articles which only reported the effects of an air cleaning device on health unless the effects on air pollutants were also reported. The selected articles were limited to those which reported the tests involving pollutant concentrations within an order of magnitude of concentrations reported by the US EPA, WHO, and others to be typical in non-industrial indoor environments. This approach may have excluded some information related to particle filtration because standard test protocols are completed at elevated particle concentrations and there is general consensus that removal efficiency is not affected by standard test concentrations.

Only demonstrated changes of concentration of one or more pollutants due to the use of an air cleaning device were considered, where "demonstrated" means that the methodology was validated and other effects such as air leakage and natural decay were considered. Demonstrated changes in odor intensity or perceived indoor air quality were also considered as evidence in this review.

3. Literature review

The scientific literature was gathered by searching through the following databases: ISI Web of Science (1910–present), Science-Direct (1823–present), MEDLINE (1965–present) and Engineering village 2 (1884–present). Google Scholar was used as a supplementary search. As a source of search records, the following keywords were used:

- Keywords related to air pollutants: formaldehyde, benzene, toluene, volatile organic compound, semi-volatile organic compound, total volatile organic compound, VOC, SVOC, TVOC, ammonia, carbon monoxide, gaseous pollutant, particulate matter, particulates, gas-phase pollutant, particle, dust, PM_{10}, $PM_{2.5}$, odor, bacteria, virus, fungi, fungus, microorganism, mold, pollen, droplet, droplet nuclei, aerosol, bio-aerosol, air pollutant, air contaminant, airborne pollutant, airborne contaminant, nitrogen oxides, CO, NO_2, nitrogen dioxide, nitrogen monoxide, NO_x, sulfur dioxide, tobacco smoke, amoebae, algae, mite, protozoa, insect feces, arthropods, asbestos, respirable suspended particulate, RSP, ozone.
- Keywords related to air cleaning: air filter, filtration, high efficiency particulate air, HEPA, adsorption, ultraviolet, UV, ultraviolet germicidal irradiation, UVGI, photocatalytic oxidation, photocatalytic oxidation, PCO, UVPCO, thermal catalytic oxidation, TCO, catalysis, catalyst, plasma, ozone, botanic, air cleaning, air purification, air purifier, air ionizer, ionic air purifier, Electrostatic precipitator, activated carbon, zeolite, molecular sieve.
- Keywords related to indoor environments: hospital, home, house, dwelling, residence, apartment, office, residence, school, building, aircraft, cabin, car, ship, subway, church, jail, indoor air, indoor, indoor environment, enclosure, room, vehicle, train, railway, clinic, classroom, university, laboratory, barrack, castle, temple, airport and stadium.

The bibliography of retrieved articles was also reviewed to identify references that were otherwise missed.

Articles and/or publications were considered for inclusion based on the following criteria:

- Original research articles in English;
- Articles relevant to the key research questions identified;
- Publications up to June 2009;
- Textbooks, design guidelines, standards, and review articles were excluded;
- Articles without information on indoor air pollutants were excluded;
- Abstracts and purely descriptive articles without a detailed analytic component were excluded;