Time for HVAC-industry to Breathe in Lifes through Healthier Indoor Air

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The World Health Organization (WHO) report "The Right to Healthy Indoor Air (2000)" states: "Indoor air quality is an important determinant of population's health and wellbeing. Exposure to hazardous airborne agents present in many indoor spaces causes adverse effects such as respiratory disease, allergy and irritation of the respiratory tract. That is why our responsibility is to provide healthy indoor environment for occupants."

We breathe 15 kgs of air every day. It is vital for our health to make sure that the air we breathe is clean - as it is to make sure that the water we drink (3 kgs) is safe or food we eat (1 kg) is healthy. Modern people spend 90% of their time indoors. It is therefore essential to make sure that the indoor air is clean – and in particular in Asia, cleaner than outdoor air.

Currently, all international indoor air and ventilation legislations are based on the assumption that outdoor air is cleaner than return air from the building. This is why typically indoor air quality (IAQ) is improved by increasing the "fresh air" intake through mechanical ventilation system or by improving the natural ventilation strategy. Ventilation also assists in room air temperature management - especially in naturally ventilated buildings without mechanical cooling. This is a well-accepted method in Western countries, where ambient air quality outside city centers is relatively clean and cold. This is not the case in India, where ambient air is the most polluted in the world, especially in terms of particulate pollution and also often hot and humid. Therefore, the purification and conditioning of the ambient air is especially important before taken indoors.

Outdoor Air Pollutants are the Basis of Human Exposure

Outdoor air intake is important in buildings to provide enough oxygen and remove breathing emissions like carbon dioxide and other impurities from indoor spaces. Dry outdoor air contains 78% nitrogen, 21% oxygen, 0.9% argon, 0.04% carbon dioxide. But, we often forget that ambient air we take into a building has many harmful substances too. Ambient air pollutants can be categorized into three major groups:

- **Gases** like carbon dioxide, carbon monoxide, nitrogen oxides, sulphur oxides, volatile organic compounds (VOCs), radon and ozone;
- **Particulates** like saw dust (dia >50 µm), coarse particulates (dia 5-10 µm), fine particulates (dia 0.5-2.5 µm), ultra-fine particulates (dia 0.1-0.3 µm) and lead dust (dia 0.1-2.5 µm);
- **Bio-aerosols** like bacteria (dia 0.5-10 µm), viruses (dia 0.01-0.1 µm), pollen (dia 5-100 µm) fungi (dia 2.5-10 µm) and molds (dia 2.5-50 µm).

Sulphur dioxide (SO_2) is produced in various industrial processes as-well-as coal and petroleum combustion. Nitrogen dioxide (NO_2) is expelled from high temperature combustion. Carbon monoxide (CO) is a colorless, odorless, toxic gas that is a byproduct of incomplete gas, coal or wood combustion. Vehicular exhaust is a major source of carbon monoxide in urban environment. Volatile organic compounds (VOCs) are emitted as gases from certain solids or liquids and include a variety of chemicals. VOCs are significant greenhouse gases and also harmful for humans – e.g. benzene is carcinogenic and toluene in high concentrations can cause severe neurological harm. Benzene sources are environmental tobacco smoke, car exhaust, building materials, paints, etc. Toluene is added to petrol, used to produce benzene and used as a solvent. Methane is emitted by natural sources such as wetlands, as-well-as human activities such as leakage from natural gas systems and the raising of livestock. Ground level ozone (O_3) formed from NO_x and VOCs.

Today major sources of lead in the outdoor air are metals processing and cars & aircraft operating on leaded fuel. As a result of regulatory efforts to remove lead from motor vehicle petrol in many countries, there has been decline in lead concentration in ambient air. Lead in the air is a problem not only because people may breathe it in, but also because people, particularly children, can swallow lead dust that has settled onto various surfaces they play around.

At the moment in Asia, particularly in China and the Indian subcontinent region, the main ambient air pollutant is fine particulate matter ($PM_{2.5}$). Thirteen Indian cities figure in top 20 world's most polluted cities (WHO, 2014) – Delhi being No. 1 with annual mean $PM_{2.5}$ level of 153 µg/m^3. Other cities have also very high annual mean levels - e.g. Ahmedabad 100, Pune 59, Bangalore and Mumbai 45, Hyderabad 38 and Chennai 24 µg/m^3. Main sources of particulate matter are traffic, energy production and various industrial processes. In India this is not only an urban problem, $PM_{2.5}$ levels are also high in smaller towns and rural areas due to e.g. hundreds of millions of challahs and farmer's burning biomass in fields. The WHO recommended safe level is 10 µg/m^3. In comparison, $PM_{2.5}$ level in London was 16, Helsinki 8, New York 14 and Beijing 56 µg/m^3.

Various bio-aerosols like pollen, fungi and molds exists in nature, but typically in low concentrations and therefore are not a major health risk for people.

Indoor Air Pollutants and Related Health Effects

WHO reports that 1.3 million people die in India because of indoor air pollution every year. In rural areas, open-air fire cooking without chimney creates carbon monoxide indoors, which has been the main cause of mortality among women and children. Whereas, in most of the urban buildings the ambient air is one of the main sources of indoor air pollutant due to lack of air purification in air intake.

Internal sources of indoor air pollution as an example are:

- **Gases** like VOCs emitted from cleaning products, building materials, paints and furniture (especially formaldehyde), carbon monoxide from cooking and environmental tobacco smoke;
- **Particulates** like ultrafine particulates from printers & copy machines, textile fibers, asbestos and man-made mineral wool fibers in ventilation systems;
- **Bio-aerosols** like viruses and bacteria from people and mold spores from dirty sewage systems, indoor plant soil and moisture damaged building materials.

Carbon dioxide (CO_2) in indoor air is not a pollution or a health risk in typical indoor concentrations (500-1500 ppm). Carbon dioxide indoors at unusually high levels (above 1500 ppm) may lead to drowsiness, headache, or to function at lower activity levels among occupants. CO_2-level is also used as an indicator of ventilation efficiency to evaluate the indoor air quality in general, as it is relatively easy to measure online.

Solvents, paints and other building materials as-well-as cleaning products may release Volatile Organic Compounds (VOCs) into the air. Emissions are typically highest from new materials. This is why effective ventilation is critical, especially in new buildings, where continuous operation of the ventilation system is recommended, particularly during the first two years of occupancy.

Human activities, such as handling papers and fabrics, generate room dust, which can be an irritant to people susceptible to allergies, but there is no evidence of health effects among a healthy population. While on the other hand, fine and ultra-fine particulates contains microscopic droplets that are so small that they can get deep into the lungs and cause serious health problems for humans. Scientific studies have linked particle pollution exposure to a variety of problems, including premature death in people with heart or lung disease, non-fatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, and increased respiratory symptoms, such as irritation of the airways, coughing or difficulty in breathing.

On October 17th 2013, WHO reasserted that $PM_{2.5}$ and ultra-fine particulate pollution are carcinogenic to humans and WHO Indoor Air Quality Guideline states that $PM_{2.5}$ level of 35 $\mu g/m^3$ is already associated with about the 15% higher long-term mortality risk.

Moisture damage can also create serious indoor air quality problems. Growth of mold starts on wet structures during 24 h from moisture damage. Refurbishment must be made carefully and all damaged building materials removed. It is also important to ensure that rainwater does not enter air handling units, where it can moisten air filters and insulation materials and create overflows. Condensation collection drains and pipes of terminal units, cooling coils in AHU as-well-as cooling towers and decorative fountains need to be cleaned and possible blockages cleared regularly.

Standing water and wet structures are potential places for mold growth. Molds are ubiquitous in nature, and mold spores are a common component of household and workplace dust. However, when spores are present in large quantities, they are a health hazard to humans, potentially causing allergic reactions and respiratory problems. Some molds also produce mycotoxins that can pose serious health risks to humans and animals. There is also a risk that airborne Legionella bacteria develops (20–45°C, RH 65%) and ventilation or water distribution system spreads this bacteria around the building.

How to Improve Indoor Air Quality?

Buildings may significantly increase or decrease people's air pollution exposures and therefore, are the most important factor in air pollution exposure and associated health effects. The most common IAQ problems are caused by insufficient ventilation (low air volume & poor filtration) and inadequate maintenance, as-well-as failures during construction phase. These problems can be solved by careful design, material selection, installation, commissioning and maintenance. Indoor air quality is healthy and acceptable when it does not contain contaminants in harmful concentrations and the majority of people feel satisfied.

High enough ambient air-flow rate needs to be used to ensure low enough CO_2-level in indoor environment. Typical ventilation rate e.g. in office space is 2.5 l/s, person + 0.3 l/s,m^2 and classroom 5 l/s, person + 0.6 l/s,m^2 (ASHRAE 62.1.). Fresh air-intake is also crucial to pressurize building and spaces. Positive pressure is needed in order to keep moist and dirty ambient air outside of building. In many cases in India, the return air is cleaner and drier than the ambient air and therefore, ambient air intake should be minimum.

In India, indoor air quality cannot be improved merely by increasing the ventilation rate without proper ambient air particulate filtration. Particulate air filters are classified as either mechanical filters (including electrostatically charged filters) or electrostatic precipitators.

Mechanical particulate filters remove particles from the air when particulates come in contact with the surface of filter media and adhere to the fibers. EU9 / MERV 16 fine filter removes more than 95% of fine ($PM_{2.5}$) and ultra-fine particulates. Therefore, buildings should have good particulate filtration, even though it may slightly increase the energy use in buildings. It is also crucial to ensure that filters confirm to the filtration efficiency standards, as they play a significant role in human safety in buildings. Before fine filter, a good coarse filter (EU4 / MERV 8) is needed to ensure a better performance and longer life of more expensive fine filter. Dirty filter do not reduce the filtration efficiency but it increases the pressure loss. The typical pressure loss of coarse filter and fine filter is 40-70 Pa when clean and 250 Pa when dirty (suggested economical change pressure loss).

HEPA (High Efficiency Particulate Air) filters are particulate filters that provide a very high level of filtration efficiency 99.97% for ultra-fine particulates too. HEPA filters are used in e.g. cleanroom applications but due to their high pressure loss (250-500 Pa) they are not typically used in commercial buildings.

Fiber media filtration efficiency can be increased by using electrostatic charge. However, these filters often lose their electrostatic charge over time because the particulates captured on their surface neutralizes their electrostatic charge. These filters typically have coarse filter media and therefore when the charge is lost, filtration efficiency becomes very low. Thus, unlike the mechanical filter, pressure drop for the electrostatically enhanced filter is a poor indicator of the need to change filters.

An electrostatic precipitator (ESP) is a filtration device that removes fine particulates and smoke from air by first negatively charging the dust particulates and then collecting them using the positively charged collector plates. The most basic precipitator contains a row of thin vertical wires, followed by a stack of large flat metal plates vertically oriented. The air flows horizontally through the spaces between the wires, and then passes through the stack of plates. A negative voltage is applied between wires and plates and an electric corona discharge ionizes the air around the electrodes. The ionized particulates move to the collector plates where they build up and form a layer of dust. When electricity is switched off, these dust particulates fall to the bottom of the unit. In contrast to wet scrubbers which applies energy directly to the flowing fluid medium, an ESP applies energy only to the particulate matter being collected and therefore it is more energy efficient.

Chemical filtration is required when ambient air contains high concentration of harmful gases, vapors and odors. Activated carbon has been used in the purification and filtration of gases for a long. Contaminant gas molecules in an air stream enters the large pores at the carbon surface and moves towards the smallest pores in internal surface. There are also new innovative chemical filters available where mixture of carbon and other ingredients (like desiccant and metal silicate) are used and where the structure of filter media reduces pressure loss.

Bio-aerosols can be removed from air using various technologies like electrostatic-precipitators, negative-ion-generators, UV-lights, ozone-generators or photo-hydro-ionization. These are not typically used in central ventilation system but locally in the areas where bio-aerosols are creating health problems or sensitive people occupies. However, it is important to notice that some of these technologies may not be safe to be used in occupied spaces.

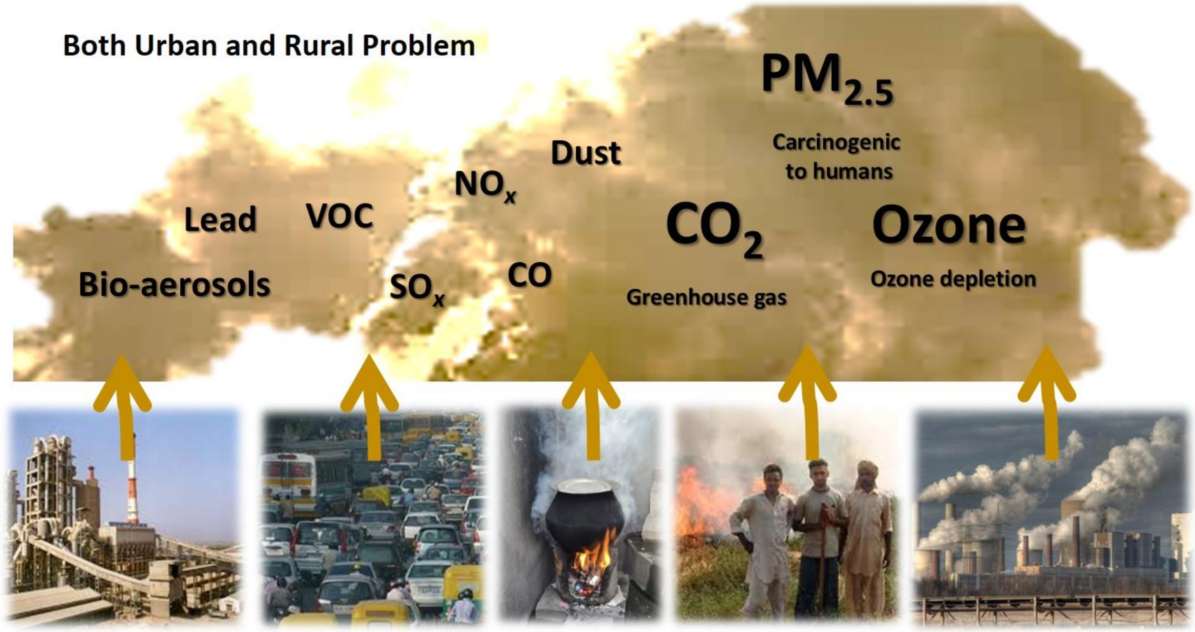
Filtration is especially problematic in naturally ventilated buildings. One option is to use portable room air purifiers. However, the need to change filters is high as all the time new polluted air enters into a building due to lack of pressurization of space that keeps dirty ambient air outside. Use of portable room air purifiers also increases the electricity consumption as each unit has its own fan and some models also electrical filters.

There is a big variety of room air purifiers in the market. In some cheaper models the filtration efficiency is too low for proper air cleaning. There are also models that produces ozone. Ozone in large amounts can neutralize strong odors (such as the smoke odor from fire damage). But according U.S. Environmental Protection Agency (EPA) ozone can be harmful to human health whether pure or mixed with other chemicals and therefore ozonizing air cleaners cannot be recommended in occupied spaces. Electrostatic air cleaners are often coupled with ionizer unit. Air purifiers that use ionization tend to produce also ozone as a byproduct, as-well-as the UV-lights used to remove bio-aerosols.

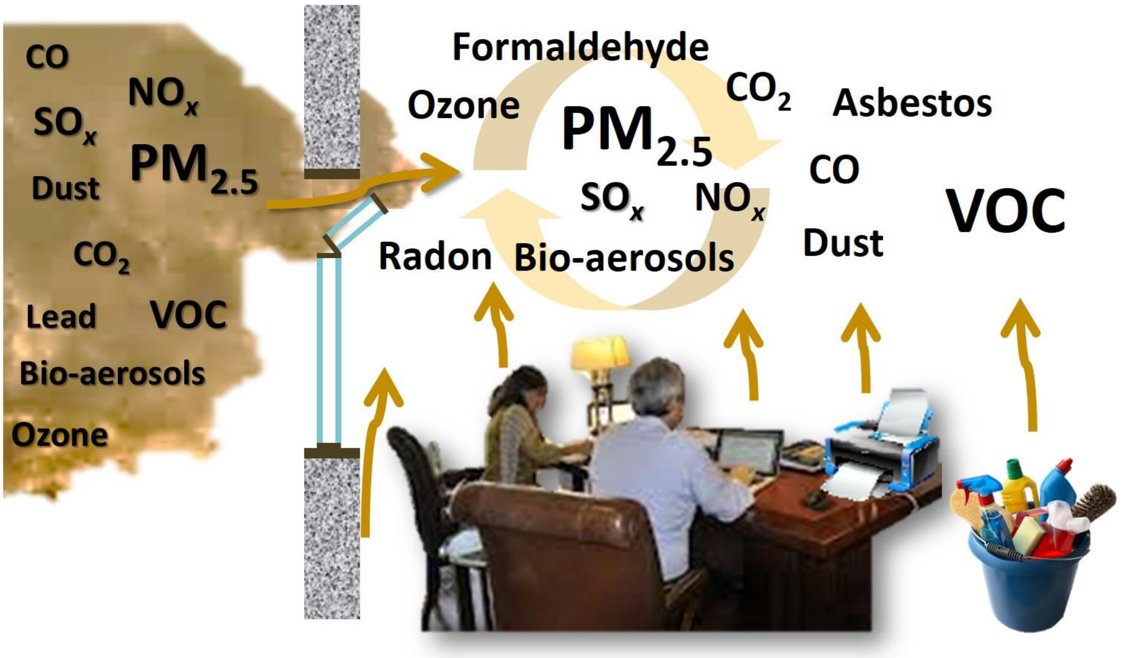
There are also technologies to remove CO_2 from the return air and add oxygen, like use of greenhouse as part of ventilation system. The ambient air needs to be first filtered from dust and then further purified through selected natural plants in greenhouse. Correctly selected indoor green plants not only add oxygen, but also help in reducing pollutants. In these cases ambient air intake could be even below the existing standard levels.

Using low emitting building materials, ventilation rates can be decreased and using demand controlled ventilation, air changes occur only in the occupied areas. Both measures have a positive impact on the energy consumption and also on the life cycle cost, e.g. investment for more expensive equipment can be paid back with savings in healthcare and energy costs.

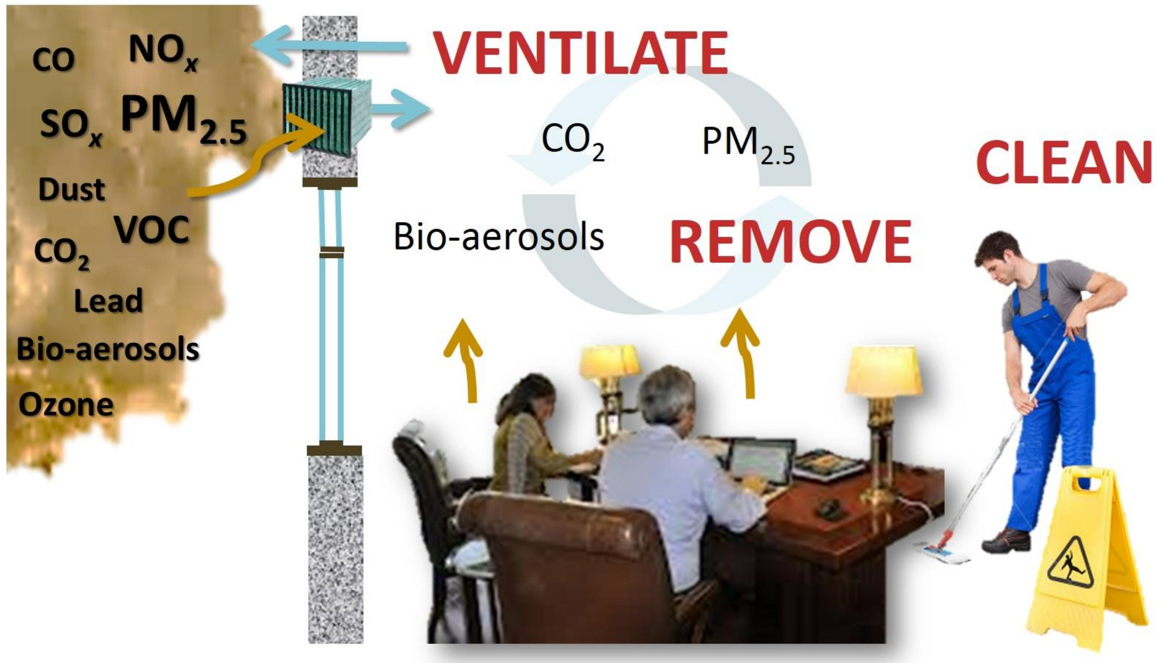
In the current scenario each one of us is looking for solutions to breathe cleaner air and save lives. All of the solutions and technologies already exist, but are yet to be implemented in India. The HVAC community in India is in key position to take the onus in endorsing IAQ policies, educating people and providing solutions for cleaner indoor air. The time is ripe for us to step forward and breathe in life through healthier indoor air.



There are various sources of ambient air pollution in India. In urban environment main sources are traffic (congestion, old cars & fuel adulteration), energy production, emissions from various industrial processes and burning of waste. In rural environments both the open-fire cooking and burning of biomass on fields create lots of particulate emissions.



Ambient air is one of the main indoor air pollution sources in urban environment if not purified properly before intake. However, there are also many internal sources like building materials, office equipment, cleaning products and people themselves.



Indoor air quality is healthy and acceptable when it does not contain contaminants in harmful concentrations and the majority of people feel satisfied. This can be achieved by ventilation spaces appropriately with purified air, removing all unnecessary internal pollution sources as-well-as maintaining the systems and cleaning the spaces properly.