

ENERGY USE IN HOUSEHOLDS: INDOOR AIR POLLUTION AND HEALTH IMPACTS

Abstract

Indoor air pollution and its health implications have gained significant attention from scientists, technocrats and policymakers in many countries across the globe. Over the last few decades, many countries have attempted to curtail air pollution levels and ensure clean air. Worldwide, nearly 12 million households use fuelwood to fulfil the energy requirement for heating and cooking. About three billion people, close to half the world's population, depend on polluting solid fuels. Many households in low-income countries use simple stoves that often lack chimneys for venting gaseous and particulates. Hence, energy use in homes has been held responsible for indoor air pollution in many parts of the globe, with tragic health consequences. Air pollution in rural households is intricately linked to energy consumption patterns. Pollutants from biomass burning persist as one of the prime factors for death and disability today. Common health problems of domestic air pollution include inflammation of the eyes, respiratory tract irritation, cardiovascular complications, lung cancer, *etc.* This chapter summarizes the various linkages between household energy use, indoor air pollution, and their health impacts. It explores the types of domestic energy, their consumption pattern, alternative fuel options and the strategies to mitigate indoor air pollution. Popularizing and promoting energy-efficient appliances, cheap and cleaner fuels can bring advantages in three ways: reducing energy consumption, curbing indoor air pollution and minimizing negative health impacts.

Keywords: air pollution; indoor air; household energy; health impacts; mitigations

Authors

Kangabam Kripaliya Devi

Ph.D. Scholar

Department of Forestry and Environmental Science

Manipur University, Imphal, India

Dr. R.S Khoiyangbam

Associate Professor

Department of Forestry and Environmental Science

Manipur University, Imphal, India

I. INTRODUCTION

Over half the global population relies on solid fuels such as wood, coal, crop residues and animal dung to meet domestic energy requirements[1]. When burned in rudimentary appliances, the incomplete combustion of solid fuels releases high levels of toxic pollutants, such as particulate matter (PM), carbon monoxide (CO), oxides of nitrogen (NO_x), Sulphur dioxide (SO₂), and volatile organic compounds (VOCs)[2]. The World Health Organization's (WHO) document on Global Air Quality Guidelines spelt out that health implications of air pollutants actually occur at much lower concentrations than previously known[3]. The guidelines call for a thorough scale-down of the previously established air quality standards to protect human health. Evidently, some of these pollutants directly or indirectly contribute to the current global warming and climate change[1]. The document recommended the permissible levels for six principal pollutants based on scientific observations of their health impacts. These pollutants are also called the criteria pollutants and include gaseous pollutants such as ozone (O₃), nitrogen dioxide (NO₂), Sulphur dioxide (SO₂), carbon monoxide (CO), particulate matter (PM) and lead. Worldwide, it is estimated that exposure to air pollution accounts for seven million premature deaths annually and harms the health of millions more[4]. Air pollution is known to affect human health, causing different health problems. However, not all humans are affected equally; females and children, particularly those in economically backward households, are more vulnerable to these health complications. Tedros Adhanom Ghebreyesus, the present Director-General of WHO, has rightly mentioned that air pollution poses a severe threat to human health in all countries but has the most significant impact on populations of low-income and middle-income countries[3]. Common health complexities due to air pollution in children include suppressed lung growth and function, infections of the lungs and aggravated asthma. Air pollution is estimated to be responsible for a disease burden par with other global health risks such as unhealthy food choices and tobacco consumption.

Amongst the various air pollutants, particulate matter having aerodynamic diameters of 2.5 and 10-micron meters (PM_{2.5} and PM₁₀) are significant as they are responsible for most air pollution-related deaths. Particles in the ultrafine fraction (PM_{2.5}) can penetrate into the deep lungs and reach the circulation, impairing cardiovascular, respiratory, and other human organs[5]. Particulate matter is produced mainly through fuel combustion for power generation, transportation, domestic energy use, industry and agriculture. In 2019, above 90% of the world's population lived in environments where concentrations of PM_{2.5} exceeded the 2005 WHO air quality guideline for long-term exposure[6]. Even though there was a significant decline in air pollution levels in countries with strong policy orientation, similar declines are less evident in regions with already good air quality over the last thirty years[7]. The United States Environmental Protection Agency (USEPA) opined that indoor air quality can be affected in many ways by climate change[8]. With the advent of climate change, increased CO₂ levels and warmer temperatures will exacerbate the problems of airborne allergens. Changing weather patterns will increase the frequency and severity of wildfires and dust storms and consequently affect indoor air quality.

II. POLLUTION SOURCES

Indoor air pollution refers to the presence of harmful pollutants in the air inside buildings or enclosed spaces. Air pollutants inside the homes may come from both indoor

(*in-situ*) and outdoor (*ex-situ*) sources. Examples of indoor sources include domestic fuel combustion (*e.g.*, gas stoves, fireplaces), building materials, furnishings, cleaning products, personal care items, cigarette smoking, *etc.* The types and amounts of pollutants emitted largely depend on the chemical composition of the material used, their quantity and usage frequency and the condition of the appliance. Besides the *in-situ* generated air pollutants, outdoor pollutants can infiltrate indoor spaces through ventilation systems, especially when the air outside is polluted. Potential outdoor sources include vehicular exhaust, industrial emissions, construction and demolition of buildings, pollen, dust, *etc.* Structures close to busy roads, industrial sites, or areas with high pollution levels are more prone to *ex-situ* pollutants entering the indoor environment.

III. MAJOR AIR POLLUTANTS

Various pollutants contaminate the air we breathe in our homes[9]. Burning biomass or coal is known to generate hundreds of harmful chemicals in the air. When burned in poorly designed and inefficient stoves or when the biomass used is not appropriately dried, indoor pollutants may shoot up considerably. Likewise, the concentration of pollutants in smoke can increase 100 times beyond the permissible limits in poorly ventilated households. Pollutants from fuel burning may include carbon monoxide, nitrogen oxides, sulphur dioxide, suspended and respirable particles and other organic matter such as polycyclic aromatic hydrocarbons, benzene and formaldehyde. Coal combustion is notorious for releasing fly ash, sulphur oxides and metals such as arsenic and fluorine[10]. Burning of solid fuels is blamed for 3.5 to 4 million premature deaths per year globally. Some common indoor air pollutants and their respective sources in residential buildings that need to be granted equal importance are:

- 1. Smoke:** Smoke is the byproduct of combustion, usually comprised of CO, CO₂, SO₂, NO_x, soot, fly ash, particulate matter, fumes, *etc.* Sources of smoke include stoves, fireplaces, furnaces, and smoking cigarettes.
- 2. VOCs:** VOCs are gases emitted from certain solids or liquids. The most commonly detected VOCs in indoor air are benzene, toluene, ethylbenzene, xylene, chloroform, carbon tetrachloride, *etc*[11]. Commonly encountered sources in the living space include paints, varnishes, detergents, air fresheners, pesticides, building materials, furniture and carpets. VOCs can have immediate and long-term negative consequences, including allergies, respiratory irritation and cancer[12].
- 3. Mold:** The airborne microbes in the form of suspended aerosols are present throughout the environment [13]. Molds usually proliferate in damp, warm, and humid indoor environments. Their concentration may easily surpass the safe limits in houses with poor air exchange rates. Mycotoxins and spores in the indoor air cause allergic reactions and respiratory disorders.
- 4. Radionuclides:** Radon is a natural radionuclide in air emitted from radioactive materials occurring in the earth's crust. They are released either from the cracks in the ground or from walls and floors made of contaminated materials. Prolonged exposure to high concentrations of radon and its radioactive daughters in air can cause lung cancer.

5. **Particulates:** Particles suspended in the air, such as dust, pollen, pet dander, and allergens, can contribute to indoor air pollution. Fine and ultrafine particulates and aerosols at higher concentrations may cause serious human health concerns.
6. **Chemicals:** Household products like disinfectants and personal care items can emit chemical pollutants such as formaldehyde, ammonia and chlorine. Long-term exposure to high concentrations of these chemicals inside our homes can be harmful.
7. **Sewer gas:** Faulty sewer system may foul the indoor air. From a toxicological point of view, ammonia (NH_3) and hydrogen sulphide (H_2S) are important [14]. At lower concentrations, the two gases cause an unpleasant odor, but at higher concentrations, they can numb the human olfactory cells, disorienting the ability to detect the odors further. The estimated odor threshold of H_2S is in the range of 0.004 to 0.03 mg m^{-3} (USEPA, 2003) [15].
8. **Other pollutants:** Other commonly occurring contaminants and their sources include: deodorizers (p-dichlorobenzene), lavatory cleaners (2-butoxyethanol, limonene, 2-butanone), overheated non-stick pans (Polytetrafluoroethylene and toxic fumes), etc. Many of these pollutants may exceed the prescribed safe limits at specific points.

IV. ENERGY USED PATTERN IN HOUSEHOLDS

Almost three billion people worldwide rely on biomass (mainly wood, charcoal, crop residues, and dung cake) and coal as domestic energy sources. Without decisive political action, it is expected that by 2030, 2.1 billion people across the globe may have no access to clean fuel and technology [16]. Energy use patterns in households can vary considerably with geographic location, climate, family size, lifestyle, and the types of appliances and equipment used. Similarly, there may be a wide temporal variation in the energy consumption pattern of a given area. Knowing energy usage patterns can help households determine areas where they might reduce their consumption. Implementing energy-saving habits and optimizing overall energy management can reduce energy bills and decrease environmental impacts. Development programs focusing on electrification, propagation of renewable energy and energy-efficient technologies can play a vital role in improving energy use patterns.

Some points which reflect the contemporary energy use patterns in rural households are given below:

1. **Cooking:** Cooking typically accounts for a significant portion of household energy consumption in rural areas. Due to limited access to modern technologies, traditional cooking methods on open fires are still prevalent. Transitioning to cleaner and more efficient cooking technologies, such as improved cook stoves, and switching to cleaner energy alternatives, can improve indoor air quality and minimize health hazards [17].
2. **Heating:** In cold climates, people rely on traditional heating methods for warming space and water during winter. Improved housing technologies with proper insulation and the right fuel choice can reduce energy consumption and indoor air pollution.

3. **Lighting:** In remote areas with unreliable access to electricity, lighting options often include kerosene lamps, candles, or solar-powered lamps. Relying on fossilized carbon may generate indoor air pollutants like soot, fly ash, PAH, and other toxic gases. Solar-powered lighting, such as solar lanterns or home solar systems, can provide cleaner, safer, and more sustainable lighting.
4. **Agricultural activities:** Traditionally, the energy requirement for agriculture comes from draft animals and humans. Rearing animals near human habitation may cause indoor air pollution due to improper waste disposal. Harmful gases from such organic wastes include H_2S , NH_3 , and a host of other toxic gases besides unpleasant odor. Smoke generated from burning cowshed litter is another problem.
5. **Temporal variation in Energy Consumption:** Indoor air pollution due to domestic energy use showed a marked diurnal variation. The level of pollution peaks twice, once during the morning and the other during the evening. Energy demand tends to be lower during other hours when occupants are out for work. Household energy use patterns change with seasons primarily due to differences in energy need, cost, and availability of fuels. In colder months, household energy consumption increases for water and space heating, besides the need for day-to-day activities.

V. FACTORS INFLUENCING INDOOR POLLUTION

Factors influencing indoor air pollution due to domestic energy consumption can be viewed from two broad categories: direct and indirect. All the sources of pollutants inside the house can be considered as direct factors. Indirect factors, on the other hand, do not emit pollutants themselves but can potentially influence the availability, concentration, and distribution of the pollutants. Anthropogenic behavior and activities as an indirect factor could considerably influence indoor air pollution. Temporal energy consumption patterns, choice of energy sources, time and place of energy use, *etc.*, are some of the human dimensions of indoor air pollution. However, many of these are intricately linked and driven by the economic status a household enjoys. Types of residential structures, appliance used, building insulation, ventilation, *etc.*, are indirect factors. Some of the factors that strongly affect indoor air quality are listed and discussed below:

1. **Structure of houses:** The type of residential structure can play an essential role in moderating and aggravating indoor air pollution. Homes in rural areas, by design, are usually more ventilated and airier than modern concrete structures. The exchange of air and pollutants between the building and the outdoor environment occurs through the gaps in walls.
2. **Building Materials and Furnishings:** Building and interior furnishing materials, such as carpets, furniture, vinyl tiles, particle boards, power cables, paints, adhesives, varnish, *etc.*, can be a source of air pollutants. Judicious choice of materials is essential as some materials release more pollutants into the air than others.
3. **Occupant Activities:** Any activity carried out by the occupant has some impact on indoor air. Activities such as cleaning, painting, using certain equipment, and even

personal activities like grooming or using certain beauty products are important. The duration, frequency, and intensity of these anthropogenic activities can considerably influence indoor air quality.

4. **Building Age and Condition:** The age, maintenance, and condition of a building can influence the level of indoor air pollution. Older buildings may have outdated ventilation systems or materials that have deteriorated over time, potentially emitting higher levels of pollutants.
5. **Economic status of the Households:** The type of energy a family can afford has many things to do with the type of pollutants in the indoor air. Families in the lower economic strata use biomass as the prime domestic energy source, often leading to higher particulate pollution than households accessible to other cleaner energy options.
6. **Meteorological Factors:** Changes in insolation, temperature, relative humidity, rainfall, and windspeed may influence the level of indoor pollutants. Temperature affects the emission rates of VOCs and other chemicals through off-gassing. High humidity favors the growth of mold, releasing allergens, while low humidity re-entrains dust particles. Rainfall washout particulates in the atmosphere, while wind patterns can influence their dispersion and settlement.

VI. HEALTH IMPACTS

Long-term deterioration in indoor air quality can lead to chronic diseases infecting the lung and cardiovascular system. Apart from this, air pollution is associated with the development of cancer in pharyngeal and laryngeal, plus other respiratory issues like asthma and tuberculosis [18]. Women and children mainly tend to suffer the ill health consequences of indoor biomass burning as they must devote more time to kitchen and household chores (IEA, 2006)[19]. Over and above, women and children are typically responsible for collecting firewood (WHO, 2022) which has another dimension of health issues. Unfortunately, women have very little say and choice over the fuels used domestically [20]. Early-life exposure to household air pollution has been linked to various adverse child health outcomes, including low birth weight and pneumonia[21]. Epidemiological studies play a vital role in evaluating the impacts of indoor air pollution exposure on human health. Hence, investigating the relationship between various indoor air pollutants and specific health outcomes in inhabitants is the need of the hour. Some of the well-established epidemiological issues attributed to indoor air pollution are:

1. **Respiratory Problems:** Indoor air pollution can lead to respiratory problems, like aggravating asthma, respiratory diseases, chronic obstructive pulmonary disease, and decreased function of the lungs. Studies have indicated associations between exposure to indoor pollutants like fine particulate matter (PM_{2.5}), volatile organic carbons, nitrogen dioxide, and formaldehyde with severe respiratory health problems.
2. **Cardiovascular Complications:** Many indoor air pollutants have been linked to severe cardiovascular complications. Fine particulate matter and VOCs, including those released from tobacco smoke, cooking, and interior items, have been related to increased risk of cardiovascular diseases like heart failure, strokes, and high blood pressure[22].

3. **Allergies and Sensitization:** Indoor allergens like dust mites, pet dander, pollen, fungal spore, fungal hyphae, and molds can be a crucial factor in worsening allergies in susceptible individuals. Exposure to these allergens can lead to allergic rhinitis, allergic asthma, and other allergic diseases.
4. **Cancer Risk:** Some indoor air pollutants have been referred to as carcinogens, meaning they can increase the risk of developing cancer in humans. For instance, prolonged exposure to radioactive material, radon, in the air can increase the risk of lung cancer[23]. Additionally, specific VOCs, such as benzene and formaldehyde, and polyaromatic hydrocarbons have been associated with various types of cancer.
5. **Neurological Effects:** Emerging research revealed the possible linkage between indoor air pollution and neurological effects. Studies have reported associations between exposure to certain indoor pollutants, for instance, PM, VOCs, chemical byproducts of tobacco smoke, and adverse cognitive and neurodevelopmental disorders in children, plus increased risk of neurodegenerative diseases like Alzheimer's and Parkinson's disease[24].

VII. MITIGATION STRATEGIES

Several steps can be initiated to lessen and mitigate air pollution in our homes. As the sources and pollutants involved in deteriorating indoor environment are numerous, any feasible mitigation strategy should be multipronged in approach. Some areas that could be explored for tackling the menace of indoor air pollution includes minimization of source strength, control of source emissions, air purification, and protecting occupants through awareness and behavioral changes. Governments and the various line departments should initiate steps to monitor indoor air pollution, frame appropriate legislations and standards for controlling pollution and popularize pollution-free energy sources and technologies by giving incentives. At the household level, occupants should minimize indoor air pollution by maintaining proper ventilation, avoiding dampness, monitoring unwanted growth of molds, maintaining cleanliness, renovating houses, *etc.* At the individual level, the occupants must change their behavior and make a judicious choice of materials at home to minimize pollution. Since indoor air pollutants primarily come from combustion, the answer to the issues largely lies in using cleaner fuel, improved *chulas*, and adaptation of zero-emission technologies. Some of the points which need to be emphasized are given below:

1. **Research and Development:** Allocation of funds for research initiatives to develop cleaner fuel and technologies may help resolve pollution problems. The study should focus on exploring locally available resources and optimizing biofuel production for efficient and low-emission combustion. An overall restructuring and reconstruction of the rural economy is vital for solving indoor air pollution problems in villages.
2. **Awareness Campaign:** Awareness campaigns and information dissemination should be taken up to inculcate knowledge on the various adverse effects of traditional fuel in conjunction with the positive impacts of switching towards cleaner energy. Updating the database on the availability, affordability, and accessibility of cleaner alternative fuels is essential.

- 3. Subsidies and Incentives:** National and local governments should give subsidies and incentives to promote cleaner fuels through tax reductions on cleaner fuels and appliances. This financial intervention can play a significant, if not a major, role in encouraging households to transition to cleaner alternative energy.
- 4. Infrastructure Development:** A thorough modernization of the existing infrastructure, which gives prompt inroads for newer and cleaner fuel, is essential, ensuring their speedy distribution and supply. This requires active collaboration among the various stakeholder, such as local communities, private enterprises, and government agencies. Modern electronic gadgets and pollutant detectors should be made available cheaply.
- 5. Training and Capacity Building:** Training and capacity-building programs should be conducted at regular intervals for all stakeholders, including local communities, technicians, and appliance manufacturers. Capacity building should emphasize handling, storing, and maintaining the fuel and appliances to ensure optimal performance.
- 6. Framing Legislations:** Government and its line departments can play a nodal role in framing and updating legislation, setting and imposing emission standards and ensuring compliance through regular monitoring.
- 7. Monitoring and Evaluation:** Air pollution mitigation measures can only be effectively framed when the database on indoor air pollution is adequately available. Hence, wide-scale monitoring of indoor air pollution is required covering as many parameters as possible.
- 8. Occupant Behavior:** Occupant behavior plays a significant role in inducing indoor air pollution. Smoking indoors, using harsh chemicals without proper ventilation, and failing to perform regular cleaning or maintenance can contribute to poor indoor air quality. Occupants should quit smoking and discourage smoking indoors.
- 9. Air Filtration:** Wherever control of pollutants at sources is not possible, air filtration may be required to purify the indoor air. The filters require cleaning at regular intervals or otherwise replaced as they can be clogged, reducing the effectiveness of removing particulate matter and other pollutants from the air.
- 10. Ventilation and Air Exchange:** Proper ventilation is crucial for maintaining good indoor air quality. Inadequate ventilation systems can increase the level of pollutants in the indoor environment. Insufficient air exchange and stagnation failed to dilute and flush air pollutants.

VIII. CONCLUSION

The pressing concern of the current generation is finding ways and technologies to counter and address the environmental issues right from our homes to issues of global magnitude. Taking into account the variety of chemicals employed in the day-to-day life of a modern man, pollution is simply inevitable. Out of the many problems humans face, indoor air pollution is an environmental issue that affects people in households across the globe. Domestic energy use pattern is one of the prime factors affecting the indoor air pollution

level in any household. Interestingly, a wide disparity in the choice of energy and appliances is observed in households within a given locality, region and among countries. On this count, the economic capability of the households is one prime factor that significantly and potentially drives the choice of energy and appliances. Consequently, there is a wide disparity in indoor air quality among households and their associated health impacts. Energy consumption-related indoor air pollutants include carbon monoxide, nitrogen dioxide, volatile organic compounds, particulate matter, *etc.* At an elevated concentration, all these pollutants can create a variety of human health havoc, like respiratory troubles, allergies, asthma, cardiovascular diseases, *etc.* Appallingly, all humans are not harmed by air pollutants equally; women, children, aged people, and individuals with pre-existing respiratory disorders are more vulnerable. The government needs to work out modalities to launch remedial programmes especially targeting the vulnerable sections. Needless to say, mitigating indoor air pollution requires adopting punitive energy-efficient practices, improving ventilation, switching towards cleaner fuels, *etc.* Regular renovation of houses, maintenance of appliances, proper designing of buildings and the sensible choice of furnishing materials are some options worth attempting. Apart from these preventive measures, installing air quality monitoring gadgets and air purifiers in living spaces can help create healthier indoor environments. Promoting mass awareness of indoor air quality and shaping people's behavior in picking household items with less air-polluting substances will be equally important.

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