Environmental Health

Potential Adverse Health Effects of Wood Smoke

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The use of wood stoves has increased greatly in the past decade, causing concern in many communities about the health effects of wood smoke. Wood smoke is known to contain such compounds as carbon monoxide, nitrogen oxides, sulfur oxides, aldehydes, polycyclic aromatic hydrocarbons, and fine respirable particulate matter. All of these have been shown to cause deleterious physiologic responses in laboratory studies in humans. Some compounds found in wood smoke—benzo[a]pyrene and formaldehyde—are possible human carcinogens. Fine particulate matter has been associated with decreased pulmonary function in children and with increased chronic lung disease in Nepal, where exposure to very high amounts of wood smoke occurs in residences. Wood smoke fumes, taken from both outdoor and indoor samples, have shown mutagenic activity in short-term bioassay tests. Because of the potential health effects of wood smoke, exposure to this source of air pollution should be minimal.

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Homeowners have turned to the use of wood as a heating fuel because of the increasing cost of oil and natural gas. This trend has been especially striking in the northeastern and northwestern United States.[1] The Washington State Department of Ecology estimated in a study in 1984 that wood was burned in 60% of Washington households, with about 2.2 million cords of wood consumed per year. Several studies have shown the potential for wood-burning stoves and fireplaces to pollute indoor as well as outdoor air. Although wood-burning stoves and fireplaces are vented to the outside, many circumstances facilitate the access of combustion products into the indoors, including improper installation, such as insufficient stack height, cracks, leaks in or poor fitting of the stovepipe, negative air pressure indoors, downdrafts, and accidents, such as wood spilling from the fireplace.[1] Also, about 70% of the outdoor wood smoke reenters the house (T. V. Larson, PhD, University of Washington, Department of Civil Engineering, unpublished data). Combustion products of wood are highly irritating to the eyes, nose, and respiratory system. Duncan and co-workers have developed data on the types of pollutants associated with wood burning (Table 1).[2]

A wood-burning stove functions differently than a fireplace. In a fireplace, as much as 90% of a fire's heat is lost up the chimney along with exhaust gases. With a stove, the air supply is controlled and the rate of combustion is also controlled so that as much as 60% of the heat produced can be delivered indoors.[3]

Sexton and associates compared particle mass, size distribution, and chemical composition of indoor and outdoor air in a residential neighborhood.[4] They found that indoor concentrations of particles were often higher than outdoor, and although wood smoke contributed greatly to the mass, other sources also were important. They also found great variation among residences in the same neighborhood.

Traynor and colleagues measured indoor air pollution and found that both airtight and nonairtight stoves produced measurable particulate matter and polycyclic aromatic hydrocarbons within the home.[5] Nonairtight stoves emitted as much as 650 μg per m^3 for a 24-hour period. Polycyclic aromatic hydrocarbons, including benzo[*a*]pyrene, are also expelled into the indoor environment. Benzo[*a*]pyrene is a known carcinogen, and any exposure above local background levels should be avoided when possible. Other pollutants can cause both acute and toxic adverse health effects. Thus, it seems appropriate to highlight our understanding of the toxic exposures involved.

Effects of Individual Pollutants

Carbon Monoxide

Carbon monoxide is one of the most ubiquitous indoor pollutants. It is a major product of tobacco combustion, and concentrations from 2 to 110 ppm have been measured in dwellings, depending on the size of the space, the number and type of tobacco products smoked, and the adequacy of ventilation.[6] An indoor level of no higher than 5 ppm has been recommended by the American Society for Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE). Incomplete combustion in fuel-rich flames due to wood burning also can produce substantial amounts of carbon monoxide, an odorless, colorless gas that has the potential to be an invisible and silent hazard. Carbon monoxide competes with oxygen on the hemoglobin molecule, forming carboxyhemoglobin. The current outdoor standard is 9 ppm for an eight-hour period, or 35 ppm for any given hour. Research on persons with coronary artery disease has shown that the amount of exercise that could be done before an attack of angina was notably shortened after carbon monoxide exposure.[7]

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Nitrogen Oxides

Nitrogen is capable of forming several types of gaseous oxides. Nitric oxide and nitrogen dioxide are found in very hot wood combustion flames, and both are toxic.[8(p103)] Nitrous oxide is not formed in normal combustion. Nitric oxide and nitrogen dioxide result from the oxygen-rich combustion of wood, coal, natural gas, or oil in a variety of stoves. These gases are very reactive and can interconvert. Nitric oxide binds to hemoglobin to produce methemoglobin. Many of the adverse effects attributed to carbon monoxide in the past may be related to the combined effect of carboxyhemoglobin and methemoglobin.[1] An indoor level of no higher than 2.5 ppm has been recommended by ASHRAE. The National Ambient Air Quality Standard for nitrogen dioxide set by the Environmental Protection Agency is 0.05 ppm averaged over one year. Nitrogen oxides may produce hematologic aberrations, affect the activity of several enzyme systems, and may also cause vascular membrane injury and leakage leading to edema. Exposures to nitrogen dioxide have been associated with toxicologic effects including pulmonary edema, bronchoconstriction, and increased infection rates. An indoor level of no higher than 0.5 ppm has been recommended by ASHRAE. Some epidemiologic evidence indicates that an increased prevalence of respiratory tract infections in young children and adult men as well as lower pulmonary function performance are associated with a history of exposure to gas stove emissions.[9] Consistent lung effects in children due to nitrogen dioxide exposure have been difficult to characterize, however.[9]

Sulfur Oxides

Sulfur dioxide is a common air pollutant from wood-burning stoves that has known airway irritating effects. Kerosene heaters have been shown to emit sulfur dioxide levels that can exceed certain occupational health standards. An indoor level of not greater than 0.5 ppm has been recommended by ASHRAE. Koenig and co-workers[10-12] have shown that adolescent subjects with asthma or exercise-induced bronchospasm or both experience large changes in pulmonary function after exposure to either 1.0 or 0.5 ppm sulfur dioxide during moderate exercise. Symptoms related to lower airway dysfunction such as dyspnea and chest tightness are generally confined to those with asthma, but healthy subjects usually complain of an unusual taste or odor.

Aldehydes

Formaldehyde is ubiquitous in our environment, and the primary indoor source of this and other aldehydes is the combustion of tobacco products. Polyurea foam insulation, particle board, and other construction products also can release formaldehyde into the indoor environment. The indoor levels reported with wood-burning stoves range from 0.3 to 1.0 ppm. The Department of Housing and Urban Development has recommended indoor levels not higher than 0.4 ppm, but ASHRAE has recommended 0.1 ppm. Formaldehyde is associated with an annoying odor and at higher concentrations—generally more than 0.8 ppm—can produce a transient irritation of the eyes and mucous membranes of the upper respiratory tract.[13] It is so soluble and rapidly metabolized that it rarely reaches the lower respiratory tract to inflict damage, except when inhaled in cigarette smoke. Formaldehyde may, on rare occasions, induce bronchial asthma at relatively high exposure doses. It appears to be carcinogenic at exceptionally high cumulative doses in rodents, but there are no conclusive studies proving its carcinogenic effects in humans.

TABLE 1.—*Emissions From Residential Wood-Fired Stoves**

Pollutant	Emission Range, lb/cord†
Particulates	3-93
SO_x	0.5-1.5
NO_x	0.7-2.6
Hydrocarbons	1-146
Carbon monoxide	300-1,220
Polycyclic organic materials	0.6-1.22
Formaldehyde	0.3-1.0
Acetaldehyde	0.1-0.3
Phenols	0.3-8
Acetic acid	5-48

*Adapted from Duncan et al.[2]
†The factor used to convert 1 lb per ton was 1.65 lb per cord.

Polycyclic Aromatic Hydrocarbons

Incompletely burned hydrocarbons from wood stoves are frequently found in indoor air. Usually they are all the gaseous or vaporizable hydrocarbons, such as hydrocarbons with 1 to 16 carbon atoms. Toxic hydrocarbons are produced if plastic materials are incinerated in wood stoves. Resulting polycyclic aromatic hydrocarbons have been shown to be carcinogenic in animal studies. Coke oven workers have exposure to polycyclic aromatic hydrocarbons in levels similar to those measured in wood smoke fumes; these hydrocarbons can serve as a surrogate for wood smoke exposure. Studies have shown that coke oven workers with 15 years' or more exposure have a 16-fold excess risk of having lung cancer as compared with the general population.[14] One of the polycyclic aromatic hydrocarbon compounds, benzo[*a*]pyrene, is a proven carcinogen in animals.

Effects of Pollutant Mixtures

Most experimental studies, because of experimental design constraints, investigate the health effects of exposure to only one agent at a time. In real life, however, people are exposed to many pollutants. The effect of the described pollutants in combination with one another is reason for additional concern. Only a few studies have been conducted with wood smoke itself. One has investigated the incidence of respiratory illness among 31 preschool children living in homes heated with wood-burning stoves as compared with 31 children living in homes heated by other means.[15] Moderate to severe respiratory symptoms such as wheezing and cough at night were notably greater in the wood stove group compared with the control group. Possible confounding factors were investigated. Approximately the same proportion of children in each group had exposure to parental cigarette smoking in the home. There was no significant difference between groups in terms of the presence of urea formaldehyde insulation or the use of humidifiers. On the other hand, another study with older children—kindergarten through sixth grade—indicated that having a wood stove in the home did not increase significantly the frequency of acute respiratory episodes.[16] In this study formaldehyde exposure, estimated from construction or remodeling products, showed a small association with respiratory symptoms. Controlling for wood stove use did not diminish the formaldehyde effect.

Epidemiologic studies of long-term exposure to wood smoke have found an increased prevalence of respiratory illness in both children and adults. A study by Anderson[17] suggested an association between wood smoke exposure and chronic lung disease in adults in Papua New Guinea. Another study with children in the same region found no difference dependent on exposure except for an excess of wheeze in boys.[18] In a study in the hill region of Nepal the prevalence of chronic bronchitis among nonsmoking women increased substantially with the duration of time per day spent near the fireplace.[19] Houses there are poorly ventilated and have no chimneys. The absence of chronic bronchitis in men was suggested to be due to the lesser amount of time they spent indoors with the burning wood.

A unique case was reported of a 61-year-old woman who had shortness of breath. She was evaluated for interstitial lung disease of an unknown cause. Bronchoalveolar lavage revealed the presence of numerous particles and fibers that were identified as wood. The patient lived in a home heated with a solid-fuel radiant room heater that roasted wood to produce heat.[20]

A review of the health effects of indoor air pollution in general with some mention of wood smoke was published in 1987.[9] Also in 1987, Dockery and colleagues[21] concluded that wood stove use was associated with an increased relative risk for respiratory illness in children selected from grades 2 through 5 in six cities where wood stove use ranged from 46% to 5%. The odds ratio was 1.32 (95% confidence intervals 0.99 to 1.76).

Particulate Matter

Wood stoves have been shown to emit substantial amounts of fine particulate matter of less than 10 μm in size. Fine particulate matter ranging in size from 0.02 to 10 μm is of concern to public health because it has been shown to be readily inspired and deposited into lungs. The finest particles are deposited more deeply in lungs where some can remain indefinitely and cause morphologic and biochemical changes.

In a study in Steubenville, Ohio, decreases in lung function in children correlated with elevated concentrations of total suspended particulate matter.[22] In a similar study in the Netherlands, lung function measurements were followed in 179 children aged 7 to 11 years during a winter season in which total suspended particulate matter was being monitored and 3% to 5% reductions in lung volume measurement were found during air pollution episodes when high concentrations of particulate matter were present.[23] Taken together, these studies suggest that declines in lung function associated with episodic exposures to total suspended particulates occur rapidly and persist for as long as two to three weeks before recovery. Particles of less than 10 μm were measured during the winter of 1985-1986 in Olympia, Washington. For a period of five days, the concentration was greater than 150 μg per m^3. Wood smoke concentration was high and responsible for 80% to 90% of the fine particles. For comparison, the concentration at the same sampling site during the summer of 1986 was approximately 20 μg per m^3.

Airborne wood smoke fumes, collected both inside and outside homes using wood stoves, have been analyzed for their toxic properties. Kamens and associates[24] have shown that wood smoke fumes contain mutagens according to the Ames short-term mutagenicity assay. The volatile organic compounds, polycyclic aromatic hydrocarbons, and especially semivolatile compounds all showed mutagenic activity, with some having as much as 100 times the activity of some well-known carcinogens. Alfheim and co-workers showed that the polar fraction of organic extracts from emissions of wood combustion had direct mutagenic activity in a modified Ames *Salmonella* assay.[25] Using another test of mutagenicity, sister chromatid exchange, Hytonen and colleagues showed the capacity of emission from an airtight residential wood stove to induce sister chromatid exchange.[26] Burnet and Insley reported that emissions from both traditional and advanced technology wood stoves caused sister chromatid exchange in mammalian cells.[27] Even though the newer stoves produced less particulate matter and carbon monoxide, the emissions from these stoves did give a positive response to the sister chromatid exchange test. In another study, air samples were collected from occupied homes using wood as an energy source and mutagenic activity was found in the air of 8 of the 12 homes sampled.[28]

Other Combustion Sources of Indoor Pollution

Whenever unvented combustion takes place indoors or venting systems attached to stoves, boilers, or heaters are malfunctioning, a wide variety of combustion products can be emitted directly indoors. Besides tobacco combustion, the primary sources of combustion by-products in residential buildings are usually space heaters, gas stoves, and gas water heaters, as well as wood stoves. Exhaust from automobiles in homes with attached carports or garages and oil and kerosene lamps and candles can be additional sources of combustion by-products.

Summary

Concern over the quality of outdoor air has been an active issue in the United States for many years. A substantial portion of the Environmental Protection Agency's budget of $300 million is devoted to concern about the contamination of our outdoor environment, such as the selenium contamination of water in California, acid rain in the Great Lakes, or a toxic waste dump in New York.[29] Though these are important issues, most people spend 80% to 90% of their time indoors, each taking well over 10,000 breaths per day to provide the necessary oxygen for human metabolism. More time is spent indoors in the harsh winter months.

The increasing use of wood as a heating fuel has precipitated concern for its potential to further pollute the outdoors but, perhaps more important, to contaminate the home. Many irritating and potentially carcinogenic compounds have been identified in wood smoke, including carbon monoxide, nitrogen and sulfur oxides, fine particulate matter, and various aromatic hydrocarbons, including benzo[*a*]pyrene. In addition to wood smoke, various other combustion sources have been identified that could directly augment the problem. Several studies have identified dozens of toxic chemicals that all appear to originate in common household activities and practices in homes.

With respect to burning wood, it is advised as well that only dry, cured wood—less than 20% water content—be burned because combustion will be more complete and fewer products of incomplete combustion will be released into the air. All stoves should be operated in a manner to produce efficient burning with minimum smoke emissions. It is important to emphasize that even the newest airtight wood

stoves emit a considerable amount of fine particles to the outdoor air.[26] Plastic and other synthetic products should never be incinerated in wood stoves. We also strongly recommend curtailing all indoor wood burning during air pollution episodes or stagnations. Finally, we propose that public health authorities increase their research and monitoring efforts directed at this important issue.

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