THE DANGERS TO HEALTH FROM Outdoor Wood Furnaces

ENVIRONMENT & HUMAN HEALTH, INC.

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Introduction

This study investigates how homes are affected by neighboring outdoor wood furnaces, as well as the health implications for the families living inside homes impacted by wood smoke.

When the weather forecast includes a warning of poor air quality, many people reduce their levels of activity and stay inside. However, many homes that are impacted by neighboring outdoor wood furnaces have air quality *inside* that is poor all the time. What can people do? This study investigates how homes are affected by neighboring outdoor wood furnaces, as well as the health implications for the families living inside homes impacted by wood smoke.

In this report, Environment and Human Health, Inc. (EHHI) explains its study, which measured potential wood smoke inhalation by people living in homes in the vicinity of outdoor wood furnaces (OWFs), also known as outdoor wood boilers (OWBs). EHHI's study monitored levels of $PM_{2.5}$ and $PM_{0.5}$ particles in each house for 72 hours.

The U.S. Environmental Protection Agency (EPA) has shown that $PM_{2.5}$ and $PM_{0.5}$ are the most common size particles in wood smoke. $PM_{2.5}$ and smaller cause the greatest health impacts because they are small enough to go deep inside the lungs, where they can not only damage the lungs, but also pass through into the blood stream,

delivering their toxins throughout the body. EHHI's study was performed over three days, for 72 hours per house, in each house that was monitored. This is the only study of its kind to date.

People have a long association with burning wood as a fuel, and because of that fact, one could easily believe that wood smoke is a natural part of our environment and is quite benign. This, however, would be wrong. Wood smoke has many of the same components as cigarette smoke, now heavily regulated because of its harmful health effects. Not only is wood smoke harmful to health, but there are currently almost no regulations restricting it or protecting neighbors who are harmed by it.[1,2]

OWFs use a heating technology that has grown in popularity, especially in the northern United States. In most cases, OWFs look like small sheds with short stacks. They are self-contained, and are connected to the building or house that they heat through underground insulated water pipes. The wood-burning shed contains a metal combustion chamber for a wood fire, surrounded by a water jacket. The fire heats the water, which is then circulated through the insulated water pipes into the house or building for heat.[3]

People have a long association with burning wood as a fuel, and because of that fact, one could easily believe that wood smoke is a natural part of our environment and is quite benign. This, however, would be wrong.

The components of cigarette smoke and wood smoke are very similar, and some components of both are carcinogenic.

Outdoor wood furnace emission problems are exacerbated by the fact that these devices cycle between oxygen-deficient and oxygen-rich burning. This causes the smoke that leaves the stack to be cool. Irrespective of the stack's height, the wood smoke will fall toward the ground and will then travel in a plume for up to one-half mile, impacting houses in its wake.[4]

Wood smoke contains particles that are so small they cannot be kept out of homes, even tightly built homes. The smoke particles enter through the windows and the doors and remain in the homes for long periods of time, impacting a family's health.[5]

As the use of outdoor wood furnaces has increased, so has the number of complaints. Neighbors have reported serious health impacts, including reduced lung function, increased asthma attacks, headaches, sinusitis, bronchitis and pneumonia. Many of the components of wood smoke are carcinogenic—and wood smoke as a whole can aggravate heart disease.[6]

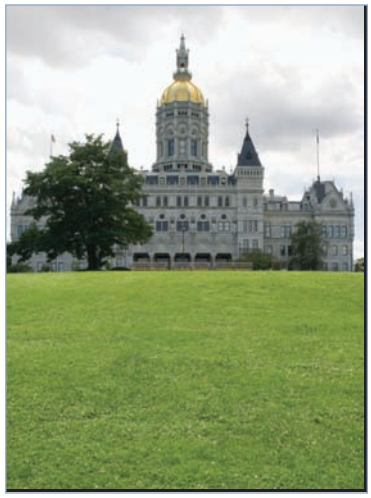
According to the Environmental Protection Agency (EPA), wood smoke includes toxic air pollutants and can cause coughs, headaches, and eye and throat irritation in otherwise healthy people.[7] Scientific literature further demonstrates that wood smoke exposure can depress the immune system and damage the layer of cells in the lungs that protect and cleanse the airways. Wood smoke interferes with normal lung development in infants and children. It also increases children's risk of lower respiratory infections, such as bronchitis and pneumonia. The components of cigarette smoke and wood smoke are very similar, and some components of both are carcinogenic.

Why outdoor wood furnaces (OWFs) emit far more smoke than other wood-burning devices

The design of an outdoor wood furnace does not allow for complete combustion, and thus generates large amounts of dense smoke. When it leaves the stack, the smoke is much cooler

than smoke from other wood-burning appliances. The firebox inside the shed of most OWFs is fully surrounded by a water jacket. This causes the wood fire to remain well below the needed 1000° F temperature for a complete burn. The slower, cooler fire is inefficient and creates a great deal of smoke, carbon monoxide and creosote.[8,9]

The Northeast States for Coordinated Air Use Management (NESCAUM) found that the average fine particle emissions from one OWF are equivalent to the emissions from 22 EPA-certified wood stoves, 205 oil furnaces, or as many as 8,000 natural gas furnaces. The report notes, to put these numbers in perspective, that a single outdoor wood-burning boiler can emit as much fine particulate matter as four heavy duty diesel trucks, on a grams per hour basis.[10] The smallest OWF has the potential to emit almost one and one-half tons of particulate matter every year.[11]



Some states have passed "set-back" regulations and stack height regulations for OWFs—but none of these measures have been able to protect human health.

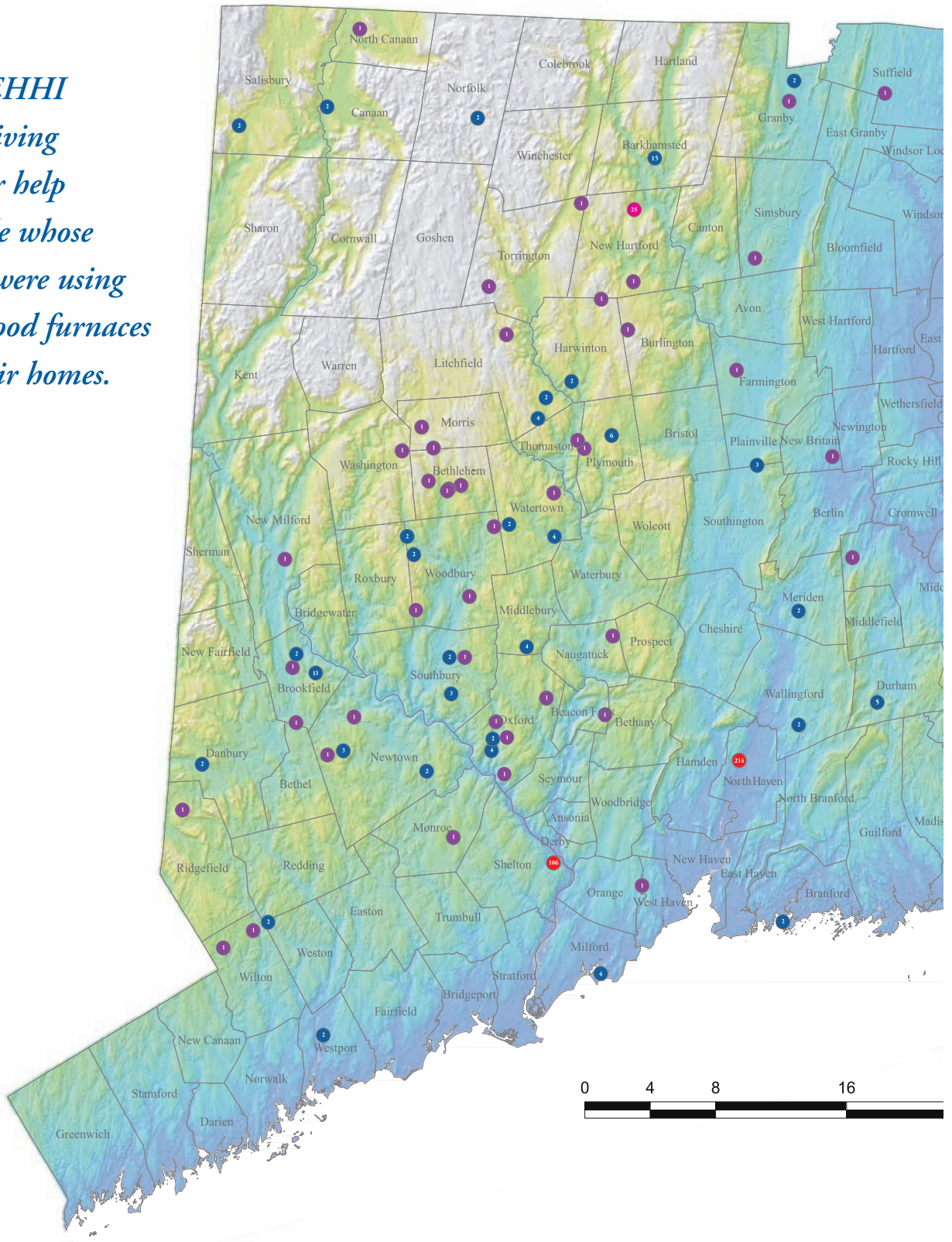
Why Environment and Human Health, Inc. undertook this study

In 2008, Environment and Human Health, Inc. (EHHI) began receiving requests for help from people whose neighbors were using outdoor wood furnaces to heat their homes. These people had sought help from their town and state officials, and only called EHHI after they had been unable to obtain any help to stop wood smoke emissions from entering their homes and making them sick. Because of the harmful effects of wood smoke on health and because federal and state agencies were not stepping in to protect health, Environment and Human Health, Inc. felt that it needed to act to try to protect the families being adversely impacted by OWFs.

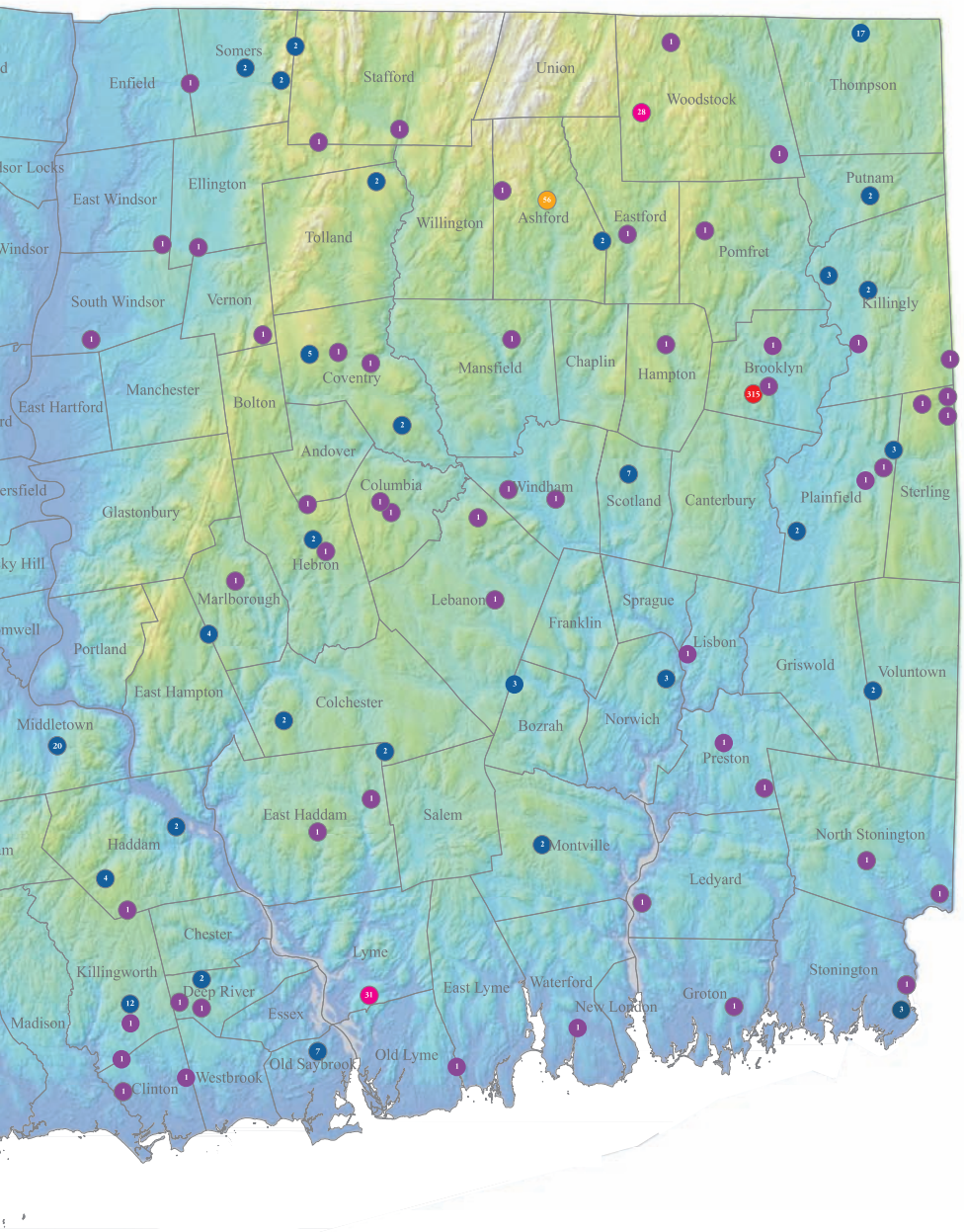
Many states have materials on their websites citing the dangers of OWFs, as well as the harmful effects of wood smoke in general. Some states have passed "set-back" regulations and stack height regulations for OWFs—but none of these measures has been able to protect human health. To date, only the state of Washington has banned OWFs throughout the state.

Outdoor Wood Smoke: Number of Complaints

In 2008, EHHI began receiving requests for help from people whose neighbors were using outdoor wood furnaces to heat their homes.



aints by Location in the State of Connecticut



Unless states take decisive action to protect their citizens, confusion and inaction will remain with regard to who has jurisdiction over wood smoke problems—and who will actually enforce wood smoke regulations.

24 32 Miles

N W E S

- 1
- 2–2
- 21–40
- 41–60
- >60

Emissions from a smoldering fire, with incomplete combustion, contain more carbon monoxide, carcinogens, organic toxicants and irritants than smoke emissions from a very hot fire that is supplied with high levels of air and oxygen.

Although some individual towns across the country have banned new installations of OWFs, this is a very cumbersome way to address the problem, as there are thousands of towns. In addition, bans by towns, going forward, do not address the problems created by "grandfathered" OWFs. In the meantime, new OWFs are being installed across the northern states in this country, creating more and more problems for people living near them *(see map, preceding page)*.

When neighbors complain to the state about an outdoor wood furnace that is *in compliance,* but is causing them harm, they are often referred back to their town officials. Unless states take decisive action to protect their citizens, confusion and inaction will remain with regard to who has jurisdiction over wood smoke problems —and who will actually enforce wood smoke regulations.

Wood smoke contains unhealthy amounts of:

- particulate matter
- dioxin
- carbon monoxide
- nitrogen dioxide
- sulfur dioxide
- hydrochloric acid
- formaldehyde
- other toxic air pollutants

Exposure to these pollutants is associated with a diverse range of harmful health effects, some of them short-term and others long-term.

How can the risks to residents' health in a home impacted by wood smoke be determined?

The amount of wood smoke inhaled determines the health risk.

The amount of contaminated air inhaled inside a house determines the health risk. In the case of complex mixtures of toxins, such as those present in wood smoke, the health effects are determined by the chemical components of the smoke emissions. Thus, the health

effects from smoldering fires are not the same as from hot "oxygen-rich" fires. Mixtures that include particulates that can be inhaled deep into the lungs put individuals at high risk. Certain gaseous toxins may be adsorbed onto the surfaces of the particulates and carried to the most sensitive regions of the lungs, where they are readily absorbed into the body. Normally, such gases would be removed in the nose and upper respiratory tract and would not reach the sensitive areas of the lungs.

The small respirable particles, 0.1 to 5 microns[12] in size, are present in all wood smoke. The particles remain suspended in the air for several hours and readily flow into houses. Thus, the particulates in the 0.1 to 5 micron size range are a surrogate for measuring the presence and intensity of wood smoke inhalation risk. Other sources of particulates in this size range include tobacco smoke, cooking particles and combustion gases from industrial sources found in ambient air.[13] Therefore, the indoor measures must be compared with background levels in the ambient air.

The inhalation of wood smoke is hazardous. Wood smoke contains irritants, systemic toxins and carcinogens. All wood smoke emissions are not the same. The levels of irritants and carcinogens are determined by the type of wood, its source and the method of burning. Emissions from a smoldering fire, with incomplete combustion, contain more carbon monoxide, carcinogens, organic toxicants and irritants than smoke emissions from a very hot fire that is supplied with high levels of air and oxygen.

Almost all burning wood and biomass release a range of particulate matter, from dense smoke to fine particulates that readily penetrate the deep lungs. Levels of particulates can be used as a surrogate for the amount of smoke emissions that enter a building. According to the EPA, toxics in the wood smoke emissions from outdoor wood furnaces include carbon monoxide, $PM_{2.5}$, PM_{10}, methane, volatile organic compounds, benzene, sulfur dioxide, nitrogen oxides, ammonia, formaldehyde, acetaldehyde, phenol, naphthalene, cresols, acrolein, 1,3-butadiene, benzopyrene, mercury, dioxins and furans.[14]

According to the EPA, toxics in the wood smoke emissions from outdoor wood furnaces include carbon monoxide, $PM_{2.5}$, PM_{10}, methane, volatile organic compounds, benzene, sulfur dioxide, nitrogen oxides, ammonia, formaldehyde, acetaldehyde, phenol, naphthalene, cresols, acrolein, 1,3-butadiene, benzopyrene, mercury, dioxins and furans.

Until Environment and Human Health, Inc. conducted this study, very little was known about how much wood smoke was actually inside homes located near outdoor wood furnaces.

Until Environment and Human Health, Inc. conducted this study, very little was known about how much wood smoke was actually inside homes located near outdoor wood furnaces. EHHI has now evaluated the indoor air quality inside a number of homes near outdoor wood furnaces. EHHI also evaluated a number of homes that were not near outdoor wood furnaces, which served as the control houses.

The critical question is the safety of those who continue to inhabit a house that has accumulated wood smoke emissions.

In order to understand the risk from the exposures occurring inside houses impacted by wood smoke emissions, it is necessary to monitor the hourly concentrations over several days to establish the patterns of air changes. To establish the added risk from wood smoke, it is necessary to compare the measurements to concentrations in control, or background, houses.

How outdoor wood smoke enters the inside of neighboring homes and the resulting health effects

The amount of smoke emissions that enter a house is dependent on the concentration of the smoke emissions outside of the house, as well as the rate at which the house exchanges outside and inside air. Typical houses in the Northeast exchange one total volume of air each hour, but can vary from one air change every two hours for "tight" houses to one air change every half-hour for a very drafty house.

Over a period of several hours, the amount of smoke emissions inside the house will reach the same concentration as in the air that surrounds the house. As a rule of thumb, it can be assumed that after one hour—in a house with good interior circulation to mix the emissions entering the house with the clean air inside it—the concentration of emissions inside a house is approximately half of that outside. The concentration inside the house will increase hourly,

until after a period of six to nine hours, the concentrations of emissions inside and outside of the house are essentially the same.[15]

Once a house is contaminated with wood smoke emissions, several hours are required to totally remove the contaminated air. The rate of removal is again determined by the number of air changes per hour. If the outside air is absolutely clean, after one air change the interior contamination is reduced by about one-half. After three to four hours, about 10 percent of the contamination is still present inside of the house. The house retains the contamination after the emissions surrounding the house have been diluted.

A study by the University of Washington in Seattle showed that 50 to 70 percent of the outdoor levels of wood smoke was entering homes that were not burning wood.[16] The EPA performed a similar study in Boise, Idaho, with similar results. The data in the charts on pages 23–27 demonstrate that similar exposures are occurring in Connecticut.

Large amounts of wood smoke, like the plumes from OWFs, cannot be kept out of neighboring houses, even those with tight windows and doors.

Key background information about wood smoke:

- Large amounts of wood smoke, like the plumes from OWFs, cannot be kept out of neighboring houses, even those with tight windows and doors.
- Wood smoke has many of the same components as cigarette smoke and, therefore, these exposures pose a real health risk for families living in the vicinity of OWFs.
- Wood smoke is a complex mixture of chemicals and particulates. It contains carbon monoxide and other organic gases, particulate matter, chemicals and some inorganic gases. Some of these compounds are toxic (aldehydes and phenols) and some are known carcinogens (benzopyrene and cresols).
- Wood smoke contains carbon monoxide (CO) gas, which at low levels can lead to serious health problems for individuals with compromised heart and circulatory conditions.

A study by the University of Washington in Seattle showed that 50 to 70 percent of the outdoor levels of wood smoke were entering homes that were not burning wood. The EPA performed a similar study in Boise, Idaho, with similar results.

- Particulate matter in wood smoke that is less than 10 microns in diameter finds its way into the alveoli in the lungs. Once in the alveoli, the particulate matter can cause structural and chemical changes, which interfere with oxygen uptake. As well, the toxic compounds and carcinogens enter into the bloodstream by way of the alveoli of the lungs.

- Episodes of short-term exposures to extreme levels of fine particulates from wood smoke and other sources, for periods as short as two hours, produce significant adverse health effects.[17, 18, 19]

- Wood smoke interferes with normal lung development in infants and children. The components of smoke increase children's risk of lower respiratory infections, such as bronchitis and pneumonia. Wood smoke exposure can depress the immune system and damage the layer of cells in the lungs that protects and cleanses the airways.

- Wood smoke causes coughs, headaches, and eye and throat irritation in otherwise healthy people. For vulnerable populations, such as people with asthma, chronic respiratory disease and those with cardiovascular disease, wood smoke is particularly harmful—even short exposures can prove dangerous.

- Children and the elderly have the highest sensitivity to wood smoke. However, no age group is without risk for respiratory problems, including asthma and chronic obstructive pulmonary disease (COPD), that result from breathing wood smoke. The effects are cumulative.

- The air impact of health exposure to wood smoke is increased two-fold during periods with stagnant air. Under such conditions, the inhaled dose levels of particulates within houses approach the hazardous level found in regulated work sites by OSHA. EHHI found smoke entering houses, every day, at even higher levels.

- The particulate matter and gases in wood smoke are so small that windows and doors cannot keep them out—even the newer energy-efficient, weather-tight homes cannot keep out wood smoke. This is consistent with reports from people in the EHHI study who say their children awaken in the middle of the night having difficulty breathing.

- In 2009, the state of Massachusetts commissioned a study on the environmental impacts of burning wood for electricity. That study, conducted by the Manomet Center for Conservation Sciences, has now been released. The Manomet study shows that, per unit, wood releases more climate-damaging gases than coal.[20]

Wood burning has been promoted as a "green" energy source because growing forests can absorb the same amount of greenhouse gases that are emitted from burning wood, essentially canceling out the pollutants. The Manomet study shows that wood burning releases more heat-trapping carbon dioxide into the atmosphere per unit of energy than oil, coal or natural gas.

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Summary of the Study's Findings

States have tried to control the harmful effects of outdoor wood furnaces by legislating set-back regulations. Some states have set-back regulations of 100 feet from the nearest neighbor, while other states have set-back regulations of 200 feet. This study shows that none of the regulations that have been put in place protect the neighboring properties or the health of the families living in the homes on those properties.

- EHHI measured the two particle sizes — $PM_{2.5}$ and $PM_{0.5}$ — designated by EPA to be the most dangerous to human health. Both of these particulates were continuously recorded in each of the impacted homes for a period of three days. Both hourly averages and minute-by-minute data were collected.

- Two of the most hazardous components of wood smoke, particulate matter (PM) measuring 2.5 and 0.5μ (u) microns in size, were significantly elevated inside homes neighboring outdoor wood furnaces. High levels were present in every 24-hour period tested, in every home.

- A look at the hours of peak exposures to $PM_{2.5}$ particles in both the background houses and the impacted houses shows that House A had peak levels that were six times higher than the control houses; House B had peak levels 14 times higher than the control houses; House C had peak levels 12 times higher than the control houses; and House D had peak levels more than eight times higher than the control houses (see charts showing Houses A, B, C and D on pages 23–26, where the blue line represents background levels in control houses).

- Comparing the derived equivalent $PM_{2.5}$ particle count to the estimated EPA 24-hour air standard of 35 micrograms per cubic meter (ug/m^3) shows that House A had four times the EPA air standard; House B had nine times the EPA air standard; House C had eight times the EPA air standard; and House D had six times the EPA air standard.

- Every impacted home had many hours when $PM_{2.5}$ particles were significantly above both the levels found in the background houses and the EPA air standards.

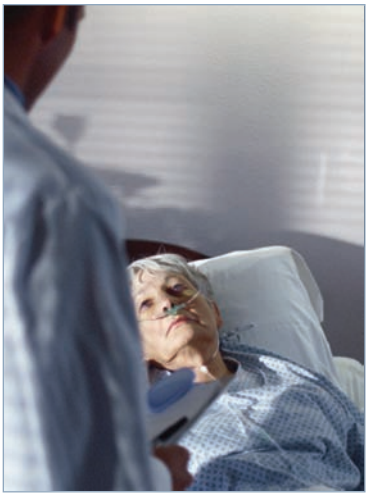
- All impacted houses had particulate exposures well above the EPA air ambient air quality standard. Levels of $PM_{2.5}$ that exceed the EPA standard are associated with asthma or COPD attacks and hospitalizations, and are also associated with increased risk of cardiovascular problems.

- An impacted house 100 ft. from an OWF had 14 times the levels of $PM_{2.5}$ compared to the background houses, and nine times the levels of $PM_{2.5}$ in the EPA's air standards.

- An impacted house 120 feet from an OWF had more than eight times the levels of $PM_{2.5}$ compared to the background houses, and six times the levels of $PM_{2.5}$ in the EPA's air standards.
- An impacted house 240 feet from an OWF had 12 times the levels of $PM_{2.5}$ compared to the background houses, and eight times the levels of $PM_{2.5}$ in the EPA's air standards.
- An impacted house 850 feet from an OWF had six times the levels of $PM_{2.5}$ compared to the background houses, and four times the levels of $PM_{2.5}$ in the EPA's air standards.
- The study shows that regulating a 200-foot setback is not protective, and does not keep wood smoke from entering neighbors' homes.
- Even the impacted house as far away as 850 feet from the OWF had levels six times that of the background houses, and four times higher than the EPA air standards, showing that a 200-foot set-back regulation in no way protects property values or human health.
- EHHI's study shows that emissions from the OWFs enter neighboring homes at all hours of the day — and it takes several hours for the particulates to clear out of the homes.
- This study shows that $PM_{0.5}$ particle exposures are also high throughout the 24-hour period, yet state and federal standards are only based on $PM_{2.5}$ particulates.
- The state and federal governments regulate particulate exposures by averaging them over a 24-hour period. Yet this study shows that the exposure peaks can be very high, and these peaks can cause health effects. The peak exposures should be examined and regulated, as well as the average exposure.
- The study confirms that windows and doors, even tight ones, cannot keep wood smoke out if it is close enough and dense enough.

Even the impacted house as far away as 850 feet from the OWF had levels six times that of the background houses, and four times higher than the EPA air standards, showing that a 200-foot set-back regulation in no way protects property values or human health.

Health Effects of Wood Smoke Exposures



Fine particulate matter is especially harmful to people with chronic obstructive pulmonary disease (COPD), increasing their hospital admission rates.[22]

Wood smoke poses risks for healthy people who are physically active outdoors. Wood smoke contains gases and other respiratory irritants linked to allergies, inflammation of the throat and sinuses, or decreased lung function.[21]

Short-term and immediate effects

Burning eyes and throat, sinusitis, bronchitis, pneumonia[22]

Long-term effects

Chronic Obstructive Pulmonary Disease

- Fine particulate matter is especially harmful to people with chronic obstructive pulmonary disease (COPD), increasing their hospital admission rates.[23]

Asthma

- Currently, 19.2 million people (8.5 percent of adults) in the United States report that they have asthma.[24] New England states have some of the highest asthma rates in the country.

  A nonprofit, public health and medical research funding organization, Health Resources in Action, produced a report entitled, *The Burden of Asthma in New England.* The report shows the very high and growing rates of asthma in both adults and children in the region. Asthmatic children are particularly sensitive to fine particulate matter and wood smoke.[25]

Cancer

- OWFs emit a number of carcinogenic chemicals. Wood smoke contains benzene, formaldehyde, polycyclic aromatic hydrocarbons (PAHs) and dioxin. Fine particulate matter also increases the risk of cancer. Analysis of data from an American Cancer Society

cohort study found that for each 10 ug/m^3 elevation in fine particulate air pollution, the risk of lung cancer mortality increased by 8 percent.[26]

Asthmatic children are particularly sensitive to fine particulate matter and wood smoke.

Cardiovascular Disease

- Mortality and hospital admissions for myocardial infarction, congestive heart failure and cardiac arrhythmia increase with a rise in the concentrations of particulate and gaseous pollutants.

  As concentrations of airborne particles increase, people with cardiovascular disease may experience increasing severity of symptoms, rates of hospitalization, and mortality.[27]

Carbon Monoxide Poisoning

- The low-burning fires of OWFs emit larger amounts of carbon monoxide than high-combustion fires. Carbon monoxide exposure is not only an immediate health risk; continuous exposures, even at low levels, can lead to neurological effects.[28, 29, 30]

Methods Used in the Research Study

Environment and Human Health, Inc. (EHHI) designed its research with two goals in mind. The first goal was to measure, with precision, the air quality in homes near outdoor wood furnaces (OWFs). This entailed setting up a particle monitor in people's homes, and also taking into account other factors that might affect air quality, such as heating and hot water systems. Data on weather conditions were also collected. The second goal of the research was to design a protocol that would be easily replicable by citizens with similar smoke concerns.

EHHI chose four homes to study from the pool of individuals who had contacted EHHI about their problems with smoke from OWFs that had been installed in neighboring houses. These four impacted families were willing to have EHHI's researchers come into their homes and were willing to abide by the research protocol. Each of the four houses in the study was between 100 and 850 feet from an OWF. Each of the families had a series of health problems that they attributed to the smoke from a nearby OWF.

EHHI's researchers measured the presence of two sizes of particles in the indoor air of the four homes — those measuring 2.5 microns and those 0.5 microns and smaller. Particles of both sizes are two of the most hazardous components of wood smoke because they are inhaled deep into the respiratory system. The device used for measurement was a Dylos Air Quality Monitor 1100 Pro. This monitor provides counts of particles (both sizes) per 0.01 cubic feet of air.

Before the measurement process began in participants' homes, they were given a description of the project. They also completed a short questionnaire to provide background information about their homes, additional potential sources of particulate matter in the air, and their health concerns. In addition, forms were provided for participants to record outdoor conditions (air temperature, wind, cloud cover) and activities inside that might increase particles in the air (vacuuming, cooking, children's activities).

At each site the Dylos Air Quality Monitor 1100 Pro was set up and stationed out of the way of daily traffic, but in a room that residents said was both exposed to the smoke and frequented by the family. Since cooking increases particulate matter in the air, kitchens

were not monitored. Depending on the house, the monitor was set up either in a bedroom or in a living room or study.

The monitor was hooked up to a laptop computer (either a Toshiba Portégé 7100 or a Presario laptop). As the monitor continuously counted the particles, minute-by-minute data were stored on the computer via its HyperTerminal. Due to recording limitations associated with the HyperTerminal, EHHI could record only about eight and a half continuous hours. The Dylos monitor itself, however, retains hourly average counts for 24 hours.

To obtain the most comprehensive array of readings possible, EHHI instituted the following data collection protocol:

- Participants were asked not to touch the monitor or the computer and to call the researchers any time they had concerns or questions. At each house, monitoring began at mid-day on the first day. Researchers then downloaded the minute-by-minute data and the hourly readings mid-day the following day (Day 2). This provided 24 hours of hourly average readings, as well as the preceding eight and a half hours of minute-by-minute data. After downloading both sets of data, the particle monitor was reset for the next 24-hour period. Day 3 followed the same protocol. On Day 4, the data were downloaded and the equipment was then removed from the home. By measuring the particles over a three-day period, EHHI was able to estimate the quality of the indoor air with confidence.

- In addition to measuring levels of both sizes of particles in the four affected homes, EHHI measured the presence of those size particles in seven homes that were not exposed to smoke from an OWF. The identical measurement protocol was followed for the non-affected houses. These measurements served as a set of comparison data. They helped to answer the question, "What would we normally expect to find in Connecticut houses during the winter season?" The data from the houses near OWFs were also compared to the EPA's Air Quality Index.

- After completing the data collection, each household was provided with two graphs reflecting its own hourly averages for the two particles sizes we measured. Both graphs also included the average hourly readings from the comparison houses that were not located near OWFs. With each family's permission, we made public the graphs representing the individual houses, but kept names and specific locations confidential.

Key Tables and Abbreviations

EPA Air Quality Index for $PM_{2.5}$ (with particulate counts scale estimate)[31]

EPA developed the Air Quality Index to compare health risks from exposures of less than 24 hours.

EPA measures the particle load, $PM_{2.5}$ particles in terms of weight (ug/cubic meter). Below is a table estimating the conversion between EPA's measures in mass and the measures in number of particles from the meter (cts/0.01 ft^3).

Air Quality	Exposure (ug/m^3)	Exposure Particle (counts/0.01 ft^3)
Good	0–20	0–45
Moderate	21–40	45–95
Unhealthy for sensitive groups	41–60	95–140
Unhealthy for all	61–80	140–195
Very Unhealthy	81–120	over 195

Keys to Abbreviations in the Following Charts

Dylos = The Dylos measuring device was a Dylos Air Quality Monitor DC 1100 Pro used to measure the particulates. The readout is the number of particles counted in 0.01 cubic feet of air. The particles are drawn through the meter by an air fan at constant rate. As they pass through a laser beam, each particle is counted. There were two particle sizes counted: 2.5 microns in diameter and 0.5 microns in diameter. Wood smoke falls into the 2.5 and 0.5 range.

CT = Counts, actual number of particles counted in 0.01 cubic feet of indoor air. The (cts/0.01 ft^3) refers to the number of particles in 0.01 cubic feet of air. That is the actual number of particles in 0.01 cubic feet exactly as it reads out on the meter dials. *(This method was used to explain the data so that a homeowner could understand the information exactly as it is shown on the meter, without doing mathematical conversions. Most scientists would have converted the data to the millions-of-particles-per-cubic-feet form. This study did not do so because it introduces another complex step and makes the information less user-friendly for the homeowners testing their own houses.)*

AVG. = The average or mean

SD = is the standard deviation of the sample. SD 54 is the average number of counts per 0.01 cubic feet of air in the background houses. SD is a measure of the variability of the hourly measurements. The data are not normally distributed, i.e., following a bell shaped curve; therefore the SD exceeds the mean.

Hours = The charts show the hourly average levels from noon to noon; e.g., 13:00 refers to 1:00 p.m.

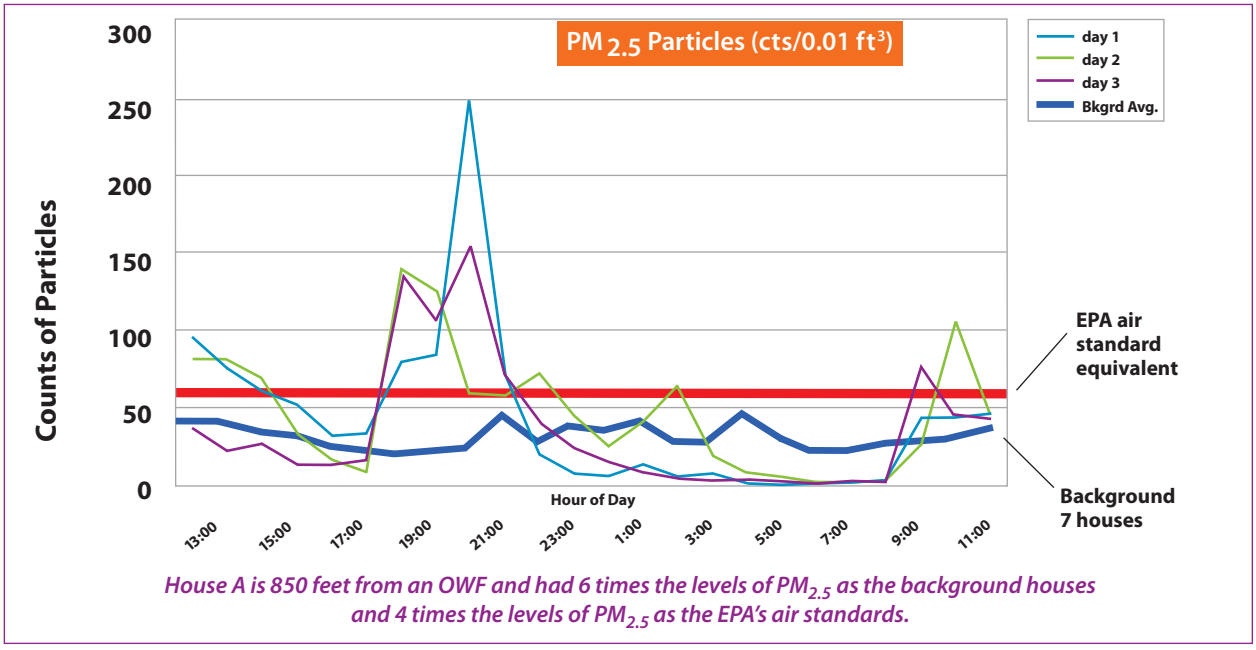
N = 308 is the total number of hours measured in the control houses with no outdoor wood furnace in the area. There were seven control houses tested for 24 hours each, some for two and some for three days.

The charts on the following pages show the impacted houses designated* A, B, C *and* D *measured over three days. Periods of very high exposure were seen for both $PM_{2.5}$ and $PM_{0.5}$ particulates in every house on every day. There are some periods of the day when the particulate matter recedes in impacted houses, but most of the time there are elevated exposures that last for hours, tending to peak in the middle of the night when residents are sleeping.

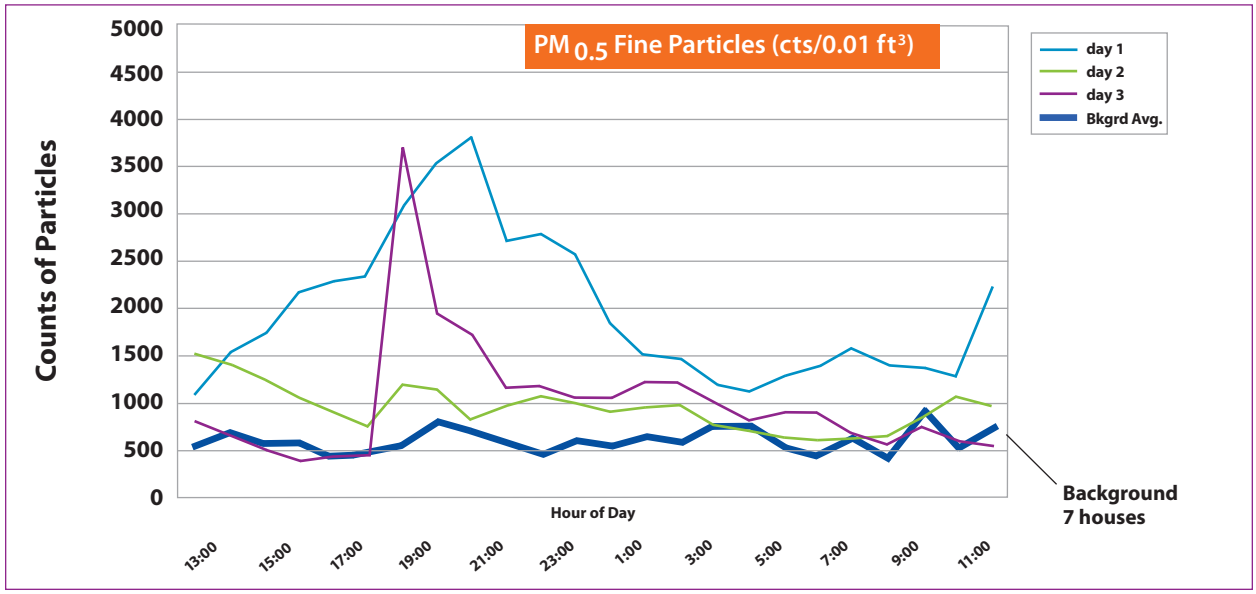
Graphic Presentation of the Study's Findings

House A

Distance = 850 feet from the neighboring Outdoor Wood Furnace, Litchfield County, Connecticut



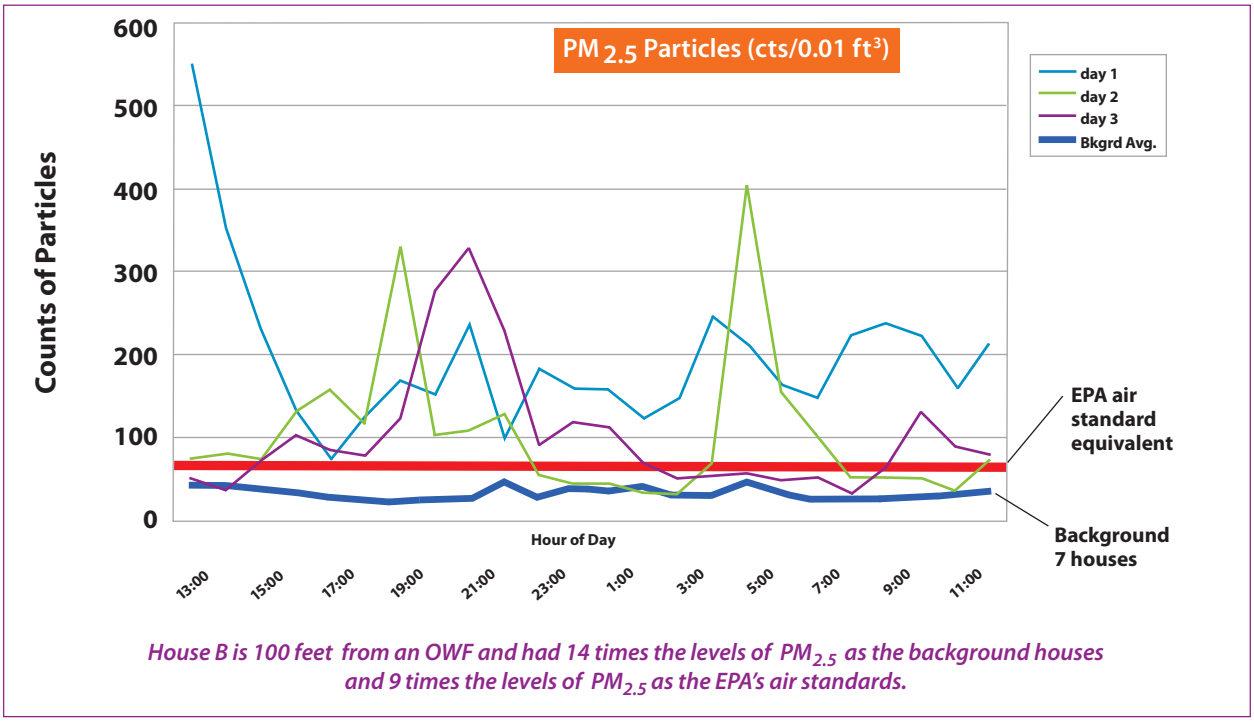
House A is 850 feet from an OWF and had 6 times the levels of $PM_{2.5}$ as the background houses and 4 times the levels of $PM_{2.5}$ as the EPA's air standards.



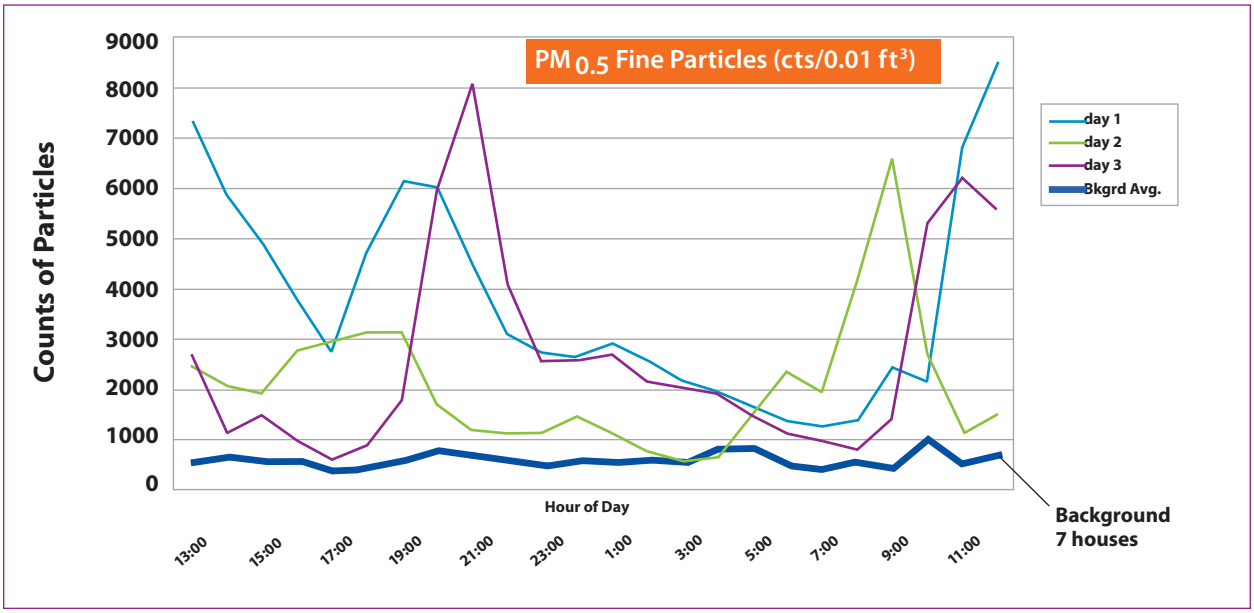
Red horizontal line = EPA federal standard for $PM_{2.5}$ expressed in ug/m³ for outdoor air. It is used for regulatory purposes. There are no standards for the inside of houses.

House B

Distance = 100 feet from the neighboring Outdoor Wood Furnace, Fairfield County, Connecticut
(The OWF was grandfathered in before the Connecticut set-back regulation of 200 feet was instituted.)



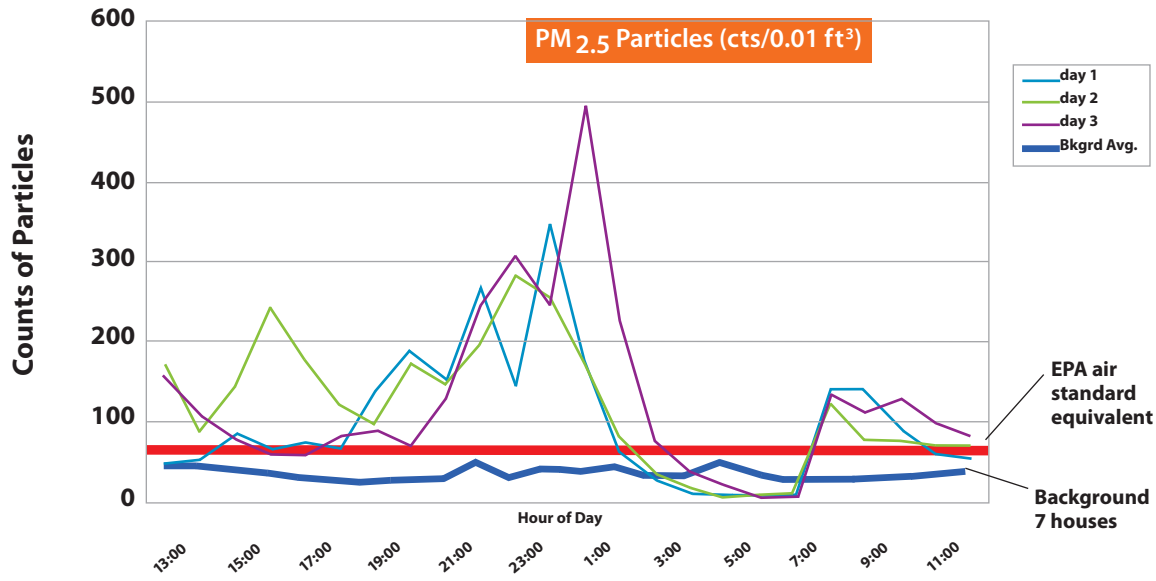
House B is 100 feet from an OWF and had 14 times the levels of $PM_{2.5}$ as the background houses and 9 times the levels of $PM_{2.5}$ as the EPA's air standards.



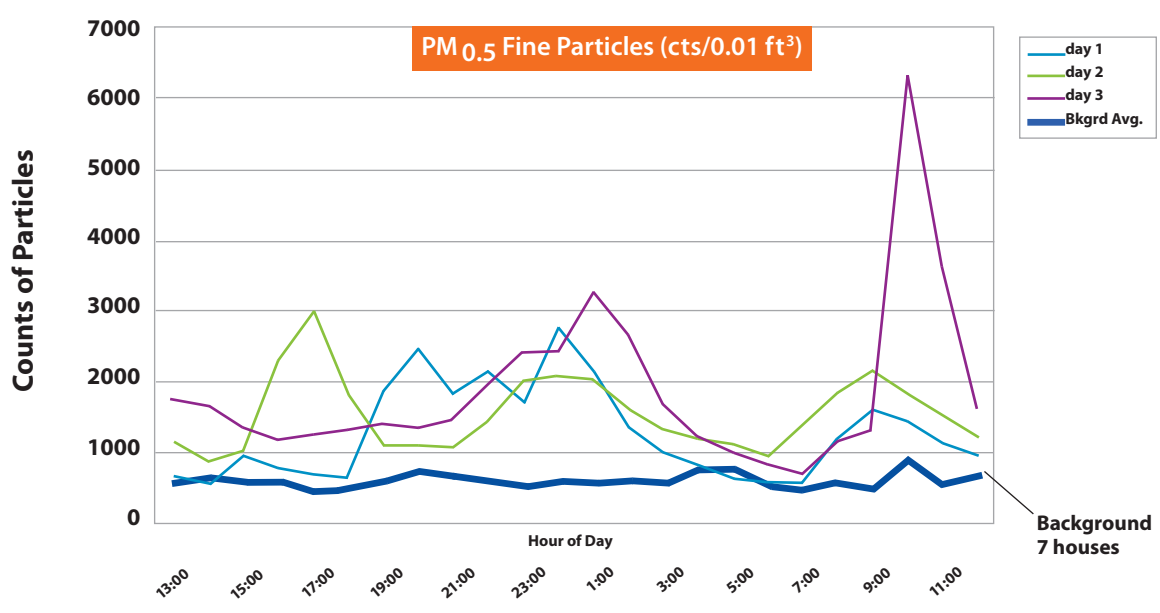
Red horizontal line = EPA federal standard for $PM_{2.5}$ expressed in ug/m³ for outdoor air.
It is used for regulatory purposes. There are no standards for the inside of houses.

House C

Distance = 240 feet from the neighboring Outdoor Wood Furnace, Windham County, Connecticut



House C is 240 feet from an OWF and had 12 times the levels of $PM_{2.5}$ as the background houses and 8 times the levels of $PM_{2.5}$ as the EPA's air standards.



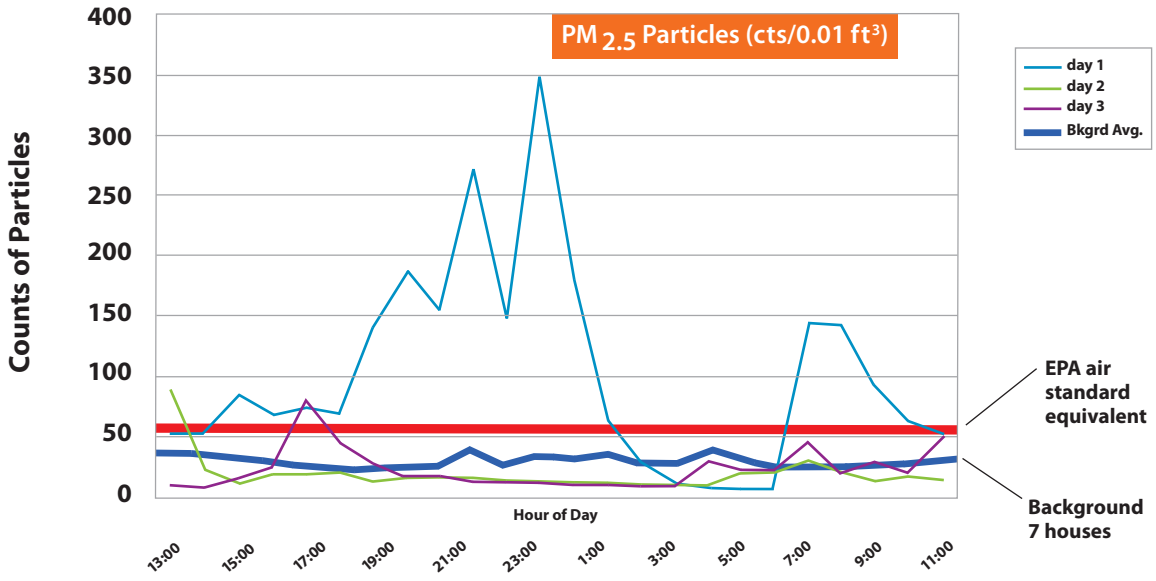
Red horizontal line = EPA federal standard for $PM_{2.5}$ expressed in ug/m³ for outdoor air.
It is used for regulatory purposes. There are no standards for the inside of houses.

House D

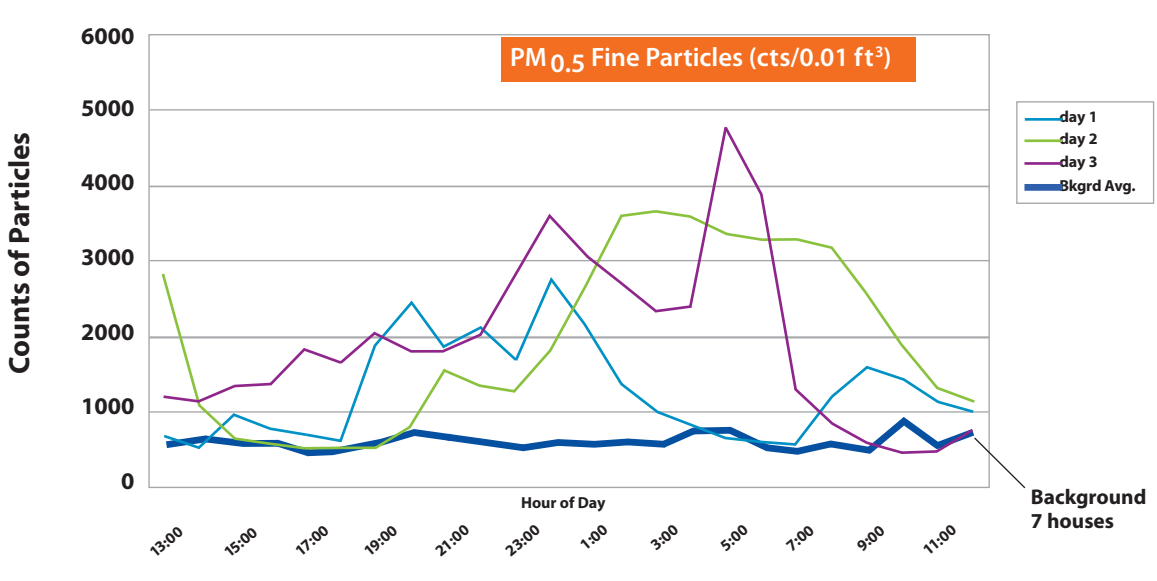
Distance = 120 feet from the neighboring Outdoor Wood Furnace

Northeastern Windham County, Connecticut

(The OWF was grandfathered in before the Connecticut set-back regulation of 200 feet was instituted.)



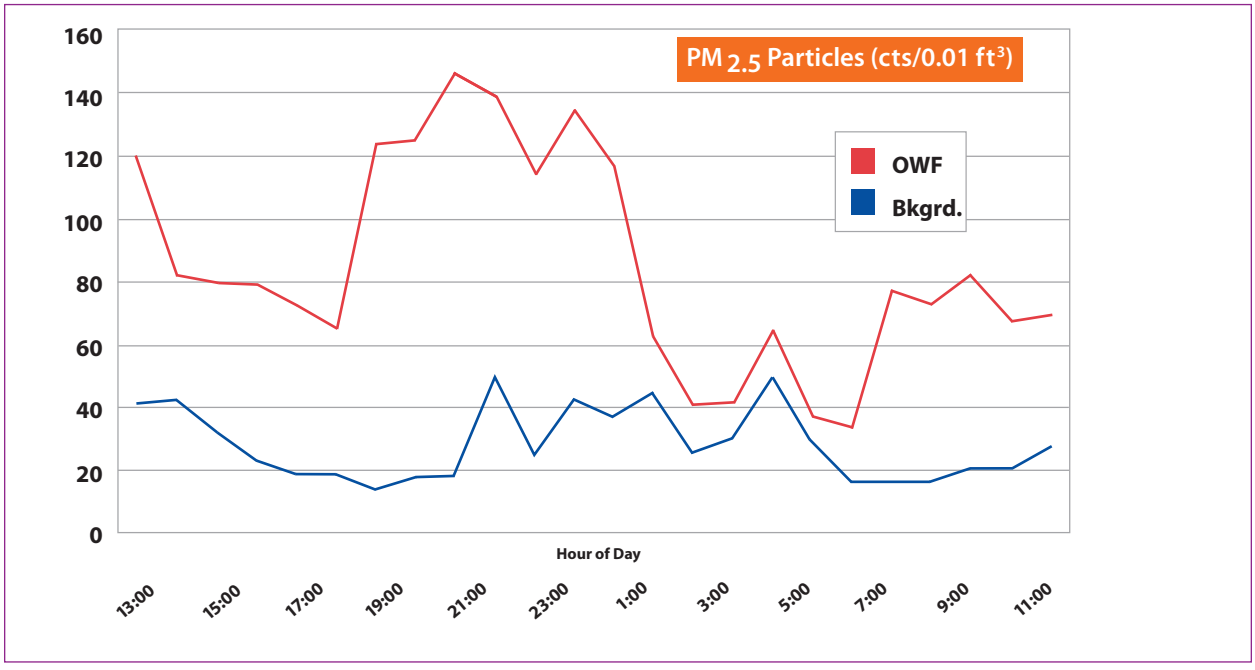
House D is 120 feet from an OWF and had over 8 times the levels of $PM_{2.5}$ as the background houses and 6 times the levels of $PM_{2.5}$ as the EPA's air standards.



Red horizontal line = EPA federal standard for $PM_{2.5}$ expressed in ug/m^3 for outdoor air.
It is used for regulatory purposes. There are no standards for the inside of houses.

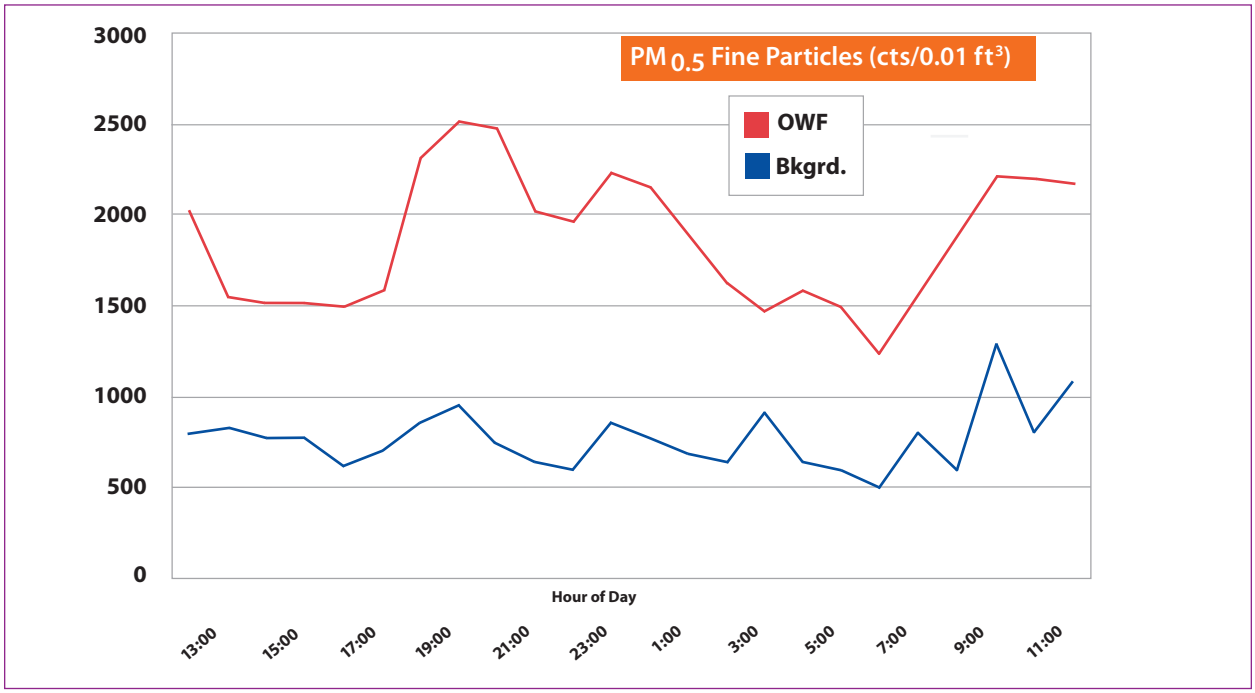
Average Hourly Particle Levels

Particulate levels inside houses near outdoor wood boilers



Red line shows impacted houses and blue shows control houses.

AVERAGE hourly $PM_{2.5}$ levels (above) and fine particles $PM_{0.5}$ (below) inside houses near outdoor wood boilers



The above two charts show dangerously high levels of smoke particulates inside houses near OWFs at all hours of the day, especially at night, compared to normal houses.[32]

Government Response to Health Issues

The response from government to complaints about the smoke from outdoor wood furnaces (OWFs) has been completely inadequate to protect human health.

The response from government to complaints about the smoke from outdoor wood furnaces (OWFs) has been completely inadequate to protect human health. Federal and state governments have acknowledged that the wood smoke from outdoor wood furnaces can cause health problems, yet they continue to allow OWFs to be manufactured in ways that produce particularly dangerous smoke, and people continue to be allowed to buy and install them. The federal and state responses to regulations have been inadequate to protect homeowners' property values and their health.

In an effort to curb the dangers of OWFs, the EPA has developed a voluntary agreement with some OWF manufacturers. The agreement asks that OWF manufacturers make cleaner models with stricter emission standards than their original OWF models. These newer models are now in the marketplace and are called "Phase II" models. Although the Phase II models have somewhat reduced wood smoke emissions, they are still emitting more than 12 times the amount of wood smoke that an indoor wood stove is allowed to emit under EPA regulations. These Phase II models are still dangerous and in no way solve the human health problems that OWFs have created.[33]

The EPA provided technical and financial support to the New England States for Coordinated Air Use Management (NESCAUM) to develop policy models that state and local governments could use to address OWF problems.

NESCAUM reported that OWFs put out dangerous levels of particulates compared to other residential wood burning devices and found that current regulations did not provide neighbors the protection they needed.

At present, much of the responsibility to address OWFs lies with the state and town governments. Some towns have acted boldly, although many have not. The state of Washington has banned the use of OWFs throughout the state. A few states, including Vermont, New Hampshire and Maine, have instituted air emission regulations. In Connecticut, only limited measures have been taken.

A look at the Connecticut Department of Environmental Protection's (CTDEP) fact sheet shows a blunt assessment of the harmful impacts of OWFs. The CTDEP asks, ***"Are OWFs harmful to the environment and human health?"*** The answer on the fact sheet is, ***"Yes."*** The CTDEP continues, "OWFs produce a lot of thick smoke, which in addition to being a nuisance to neighbors has serious health and air pollution impacts." In spite of this assessment, Connecticut has only instituted a set-back of 200 feet, with a chimney height that is higher than the roof peaks of residences located within 500 feet of the OWF.

Washington State has taken the lead in the nation by instituting a statewide ban. No other state has done so to date.

Vermont was the first state to adopt emission standards for outdoor wood furnaces in 2007. Some other states have now followed Vermont's lead and have instituted their own state standards and regulations as they try to make OWFs safer for neighbors' health. However, EHHI's research makes clear that even when OWFs are in compliance with their state regulations, the OWFs still pose a danger to the health of the families who live nearby.

In the absence of further federal or state actions, individual towns across the northern states have banned OWFs. For instance, as of the writing of this report, eleven towns in Connecticut have banned OWFs through their planning and zoning commissions. As well, many towns in New York State, Massachusetts, Wisconsin, Minnesota and New Jersey have banned them.

EHHI's research makes clear that even when OWFs are in compliance with their state regulations, the OWFs still pose a danger to the health of the families who live nearby.

Recommendations

Recommendations for the Federal Government

- The federal government should ban outdoor wood furnaces until safer technologies are found.
- If the federal government supports the idea of outdoor wood furnaces for the purpose of heating, then it should support research on how to make them safe. At the very least, the federal government should stop giving tax credits for their purchase.
- The government should determine the levels of particulates, carcinogens and carbon monoxide emanating from an outdoor wood furnace.
- The EPA's stated mission is "to protect human health and to safeguard the natural environment." With that as its mission, the agency should recommend a ban on outdoor wood furnaces until safer technologies are found.
- The federal government should set air safety standards for inside air, including $PM_{0.5}$ particles, just as it has set standards for outside air.
- Healthful air emission standards should be applied to outdoor wood furnaces.

Recommendations for State Governments

- States should ban outdoor wood furnaces until safer technologies are found.
- States should set air standards that are stringent enough to protect human health, and require OWFs to comply.
- States should add "wood smoke" to their Public Health Nuisance Codes so that state health departments and local health departments are required to enforce wood smoke nuisance cases.
- States should put outdoor wood furnace information on their websites and explain why OWFs are dangerous to human health.
- States' air standards should take into account peak exposures, as well as the current 24-hour average exposures.

Recommendations for Towns

- Towns should ban outdoor wood furnaces through their planning and zoning commissions or appropriate governmental agencies.
- Local health departments should enforce wood smoke public health issues in ways that protect an individual's health.

Recommendations for Individuals

- People should find other ways to heat their homes rather than installing outdoor wood furnaces, which harm neighbors' health and property values.
- People should work with their town planning and zoning commissions to have outdoor wood furnaces banned in their towns.
- People who are being harmed by an outdoor wood furnace should contact their state or local health department and ask to have the offending outdoor wood furnace closed down under their state or local public health nuisance code.
- Individuals living in homes impacted by wood smoke from outdoor wood furnaces might want to purchase an air monitor that measures and records the particulates inside their houses. Monitors such as this sell for about $250. See pages 32–34, Appendix A, for instructions for using a monitor of this type. Having actual documentation of the smoke infiltration inside a home may cause state or local health departments, or other government agencies, to act in ways that will protect human health.
- Patients who are being treated for respiratory issues should discuss their exposures to an OWF when being evaluated by their physician, as other health issues related to these exposures might be involved.

Healthful air emission standards should be applied to outdoor wood furnaces.

Appendix A.

Instructions for Home Monitoring with the Dylos 1100 Pro Air Quality Monitor

The Dylos monitor stores up to eight hours of minute-by-minute data, and up to 24 hours of hourly averages. It also stores daily averages for up to 30 days. To make the best use of the data, it is advisable to download it to a laptop computer on a regular basis. The following protocol requires downloading data once every 24 hours. ***Note:*** **This monitor records data for 24 hours. If the data aren't downloaded, the monitor begins to record over the earlier data.**

Be sure to begin your monitoring project at least 24 hours in advance of when you plan to download the first day of data (Day 1). The device records eight hours of minute-by-minute data for the most recent eight hours of monitoring. For example, let's say you set up your monitor to begin recording on Day 1 at noon. On Day 2, you download the data from the monitor onto your computer at noon. This will give you hourly averages for the past 24 hours, as well as minute-by-minute data beginning at about 4 a.m. that morning. This will occur again on Days 3 and 4.

Getting Started

Place the monitor and laptop computer in a room you think is affected by smoke, but not in a kitchen, a room with a woodstove or fireplace, or a room with lots of activity, such as a playroom. Cooking, heating and kids' play will create or stir up particulate matter and skew the data you get from the monitor. Place the instrument and laptop three to six feet off the floor, where they are easy to access but out of the way of foot traffic.

- Plug in the Dylos monitor.
- Attach monitor to the computer with the USB.
- Turn on computer. Log on.
- Go to: Start → Programs →Accessories → Communication → HyperTerminal.
- Open new HyperTerminal document.
- Save with name and date.
- Turn on the particle monitor.
- Open Excel spreadsheet. Label sheets Day 1, Day 2, Day 3. Name and save the spreadsheet.
- Monitor the house air for at least three days.

The monitor must remain connected to the computer and the computer left running with the "HyperTerminal" open. Because there is no time clock in the monitoring device, it is very important to record the time that the data are downloaded.

Download to an Excel Spreadsheet

The eight hours of minute-by-minute data

- Open the Excel spreadsheet. (Once open, you can leave it open for the rest of the monitoring period.)
- On the HyperTerminal, click "select all."
- Copy and paste the data in the Excel spreadsheet.

*(Be **SURE** to record the time and date at the top of the column.)*

The 24 hours of hourly data

- On the HyperTerminal, press "Capital D" and "Enter" at the same time.
  The last hour of minute-by-minute data is downloaded to the HyperTerminal, the last 24 hours of hourly data are downloaded to the HyperTerminal, and the last several days of daily data are downloaded to the HyperTerminal. These are appended to the end of the minute-by-minute data already on the HyperTerminal.
- Select this set of data by highlighting.
- Copy and paste in the spreadsheet that is already open. Paste the data in one of the next columns on the spreadsheet and label it with time and date. Save the spreadsheet data.

For each consecutive day, repeat the process to open, label and save a new HyperTerminal document. There is no need to create a new Excel document. There is also no need to reset the Dylos monitor because it records over the last day's data every 24 hours.

For each day, copy and save the data on consecutive sheets in the Excel document, labeled Day 1, Day 2 or Day 3, or you may want to label the sheets with the time and date you downloaded.

Save the spreadsheet every time data are downloaded, because if the power to the computer is lost, the data will also be lost. The spreadsheet data can also be saved in a backup location.

Separate the Data into Two Columns

When the data are downloaded in Excel, two numbers, representing the two different sizes of particles ($PM_{2.5}$ and $PM_{0.5}$ microns), are recorded together in one column separated by a comma (for example: 2304,88). A few steps are required to separate the two into different columns.

- In Excel, select the data column.
- Click on "data."
- Select "text to columns."
- Choose "delimited," then click "next."
- Check the "comma" box, then click "finish."

This will separate the data into two columns.

If the downloaded numbers contain more than one comma (for example: 11,820,49), there are additional steps to take. If there are just a few of these in the data, the numbers can be selected and separated one at a time, manually.

If there are several in a row, do the following:

- Select "data."
- Select "text to columns."
- Choose "fixed width," then click "next."
- On the ruler that appears above the selected numbers, use the cursor to place a line between the two numbers to be separated.
- Click "finish."

The data will separate into two columns. Label the columns by particle size.

Prepare the Data for Charts (Using $PM_{2.5}$ Data)

To convert the data to charts using Excel, it is necessary to create a corresponding column that notes "time of day." To convert the 24 hours of hourly averages for three consecutive days into a chart, as was done in this study, take the following steps:

- On a new Excel sheet, create a "time of day" column. Begin at the top with the hour at which the data was downloaded for the previous day. Going backward in time, enter the previous 24 hours (military time is recommended).
- Next, copy and paste into three consecutive columns the 24-hour data for $PM_{2.5}$ microns from the three days of monitoring. Each hour in the "time of day" column should correspond with data for all three days. There should now be one column listing hours of the day and three columns of data stretching down 24 rows—one row for each hour monitored—three columns for the three days monitored.
- Highlight the time column and the columns containing the $PM_{2.5}$ data. (Do not highlight headings if you have put them in.)
- Click "Insert."
- Click "Chart."
- Click "Line Chart."
- Click "Line with data markers."
- Click "Next."

The new window has two tabs: "Data Range" and "Series." Click the "Series" tab. This screen allows you to label the lines. *Series1* will be highlighted. Click the box for *Name.* Label the first series, for example, as Day 1, or with the start date of the first 24-hour period of monitoring. Highlight *Series2* and repeat with a new name, and repeat again for *Series3.*

- Click "Next."

  In Chart Options, under "Title" you can title the chart, for example, "$PM_{2.5}$ Readings."
  In the box "Category X axis," enter "Time of Day."
  In the box "Category Y axis," enter "$PM_{2.5}$/hr."
- Click "Finish."

You can now move and resize the chart.

Repeat the above instructions to produce a chart for the $PM_{0.5}$ data.

Appendix B.

Ways to Interpret Indoor Air Assessments When Monitoring Homes Impacted by Wood Smoke

When assessing a house impacted by wood smoke, the first step is to characterize the duration and intensity of human exposure risks from particulates. The Dylos air monitor or a similar device analyzes the air inside the house to assess the emissions that have penetrated a wood smoke-impacted home.

The second step is to compare the risk from monitored indoor wood smoke exposures to risks from outdoor air, and also to compare the monitored house to indoor air in houses that are not near sources of outdoor wood smoke. (See pages 36-40.)

The three indicators used in this study to evaluate the levels of exposures are based on:

- Observations of the levels of hourly $PM_{2.5}$ and $PM_{0.5}$ particle counts in wood smoke-impacted houses compared to control houses.
- The maximum particulate counts in wood smoke-impacted houses compared to control houses.
- The six-hour inhaled dose of particulate $PM_{2.5}$. (See page 41.)

Methods of Comparison

- ***Comparisons between hourly $PM_{2.5}$ and $PM_{0.5}$ particle counts in wood smoke-impacted houses and control houses***

The U.S. EPA Health-Based Standards

The EPA set a health-based standard for $PM_{2.5}$ in 2006. The EPA standard, which is based on interpretation of a series of health studies by expert panels, is primarily used for regulatory purposes as a component of the national air monitoring program. The Clean Air Act requires the EPA to set National Ambient Air Quality Standards (NAAQS) for particle pollution (also known as particulate matter). **Primary standards** set limits to protect public health, including the health of "sensitive" populations, such as asthmatics, children and the elderly.

The EPA revised the PM standards, setting separate standards for fine particles ($PM_{2.5}$), based on their links to serious health problems, ranging from increased symptoms, hospital

admissions and emergency room visits for people with heart and lung disease, to premature death in people with heart or lung disease.

The EPA 24-hour standard for ambient air is 35 ug/m^3. The EPA standard is a mass per unit volume measurement that is equivalent to 75 to 80 particle counts per 0.01 cubic feet (values are recorded in counts per 0.01 cubic feet in the Dylos monitor). See page 22 for conversion of EPA's measures in mass to the measures in number of particles from the meter.

- ***Comparison of exposures in OWF-impacted houses to the CONTROL houses***

This option for interpretation of indoor monitoring compares the 24-hour average to the EPA's 24-hour ambient air standard. It is based on an assumption that all health risks are directly related to the average 24-hour exposures to $PM_{2.5}$. While this demonstrates the impacts of indoor air contamination, it underestimates the significance of hourly peaks over the 24-hour period, and underestimates health risks.

The table below compares the 24-hour measurements in wood smoke-impacted houses to measurements in the control houses.

Comparison of the 24-hour averages for $PM_{2.5}$ in control houses and OWF-impacted houses, from the EHHI study

# of 24-hour measurement periods	Control/background houses (cts/0.01ft^3)	OWF-impacted houses (Counts/0.01ft^3)
1	13.8	44.4
2	18.1	48.5
3	71	35.1
4	68	195.2 (exceeds EPA std.)
5	84 (exceeds EPA std.)	101.5 (exceeds EPA std.)
6	32	103.5 (exceeds EPA std.)
7	16.8	101.5 (exceeds EPA std.)
8	23	126.5 (exceeds EPA std.)
9	21.4	129.2 (exceeds EPA std.)
10	22.3	101.5 (exceeds EPA std.)
11	6.9	19.0
12	15	23.0

In this analysis, when the EPA ambient air standard (75-80 cts/0.01 ft^3) is used to estimate the risk to indoor air, it can be seen that excess exposures to $PM_{2.5}$ occur consistently inside houses in areas impacted by OWFs, but not in the control houses. The levels of $PM_{2.5}$ in OWF-impacted houses are substantially above the EPA's 24-hour standard. These levels are also significantly above both those in the control houses and the outside air measurements.

Thus, the comparison of 24-hour indoor air levels to EPA standards shows the impact of a neighborhood OWF. However, the intensity of the wood smoke exposures inside the houses at different times of the day is not observed for periods of less than 24 hours.

- ***Comparison to the EPA Air Quality Index scale for exposures of less than 24 hours***

  The Air Quality Index (AQI) assesses the impact of exposures lasting less than 24 hours. The AQI focuses on health effects individuals may experience within a few hours or days after breathing polluted air, and provides a warning if the 24-hour average fine particle ($PM_{2.5}$) concentration is *"unhealthy for sensitive groups"* — above 40.5 ug/m^3.

The EPA's table of break points for periods of less than 24 hours is shown below.

C_{low}*	C_{high}	Category
0	15.4	Good
15.5	40.4	Moderate
40.5	65.4	Unhealthy for sensitive groups
65.5	150.4	Unhealthy
150.5	250.4	Very Unhealthy
250.5	350.4	Hazardous
350.5	500.4	Hazardous

*C = concentrations of $PM_{2.5}$ in ug/m^3

The EPA warns that both fine and coarse particles can cause a variety of serious health problems. When exposed to these particles, people with heart or lung diseases and older adults are more at risk for hospital and emergency room visits or, in some cases, even death. **These effects have been associated with short-term exposures lasting 24 hours or less.** Long-term exposures of a year or more have been linked to the development of lung diseases, such as chronic bronchitis.

Particles can aggravate heart diseases, such as congestive heart failure and coronary artery disease. If you have heart disease, particles may cause you to experience chest pain, palpitations, shortness of breath and fatigue. Particles have also been associated with cardiac arrhythmias and heart attacks.

Particles can aggravate lung diseases, such as asthma and bronchitis, causing increased medication use and doctor visits. If you have lung disease, and you are exposed to particles, you may not be able to breathe as deeply or vigorously as normal. You may have respiratory symptoms, including coughing, phlegm, chest discomfort, wheezing and shortness of breath. You also may experience these symptoms even if you're healthy, although you are unlikely to experience more serious effects. Particles can also increase your susceptibility to respiratory infections.

The EPA's system of health warnings for different exposures

Air quality	ug/m^3	cts/0.01 ft^3	Health Warning
Good	0 to 15.4	0 to 35.4	Air quality is considered satisfactory, and air pollution poses little or no risk
Moderate	15.5 to 40.4	35.5 to 92.4	Air quality is acceptable; however, for some pollutants there may be a moderate health concern for a very small number of people who are unusually sensitive to air pollution.
Unhealthy for Sensitive Groups	40.5 to 65.4	92.5 to 150.4	Members of sensitive groups may experience health effects. The general public is not likely to be affected.
Unhealthy for All	65.5 to 150.4	150.5 to 345.9	Everyone may begin to experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy	150.5 to 250.4	346 to 575.9	Health alert: everyone may experience more serious health effects

The EPA's assessment in support of the Air Quality Index points out that exposures of less than 24 hours can have effects on the lungs and heart, and increase respiratory infections. Therefore, it is necessary to examine exposures of less than 24 hours.

- ***Comparison of the hourly averages for $PM_{2.5}$ in control houses and OWF-impacted houses during different periods of the day, from the EHHI study***

There are four distinct periods in the day: **afternoon hours** (12 to 5 p.m.); **evening hours** (6 to 11 p.m.); **night hours** (midnight to 5 a.m.); and **morning hours** (6 to 11 a.m.). When the wood smoke and particulate-induced physiological actions of clinical significance are applied to these periods, it gives a quantitative measure of the risk from $PM_{2.5}$ exposures at different times of the day.

$PM_{2.5}$ levels during the different periods of the day in houses impacted by OWFs

House/Day	Afternoon	Evening	Night	Morning
A/1	59.7	86.2	7.2	24.6
A/2	50.8	84.3	28.2	31.7
A/3	23.3	90.3	7.8	29.8
B/1	243.2	164.3	173.7	200.2
B/2	105.0	127.2	121.7	60.8
B/3	69.8	193.3	65.8	73.2
C/1	66.3	206.3	49.3	83.3
C/2	159.3	193.8	56.3	84.4
C/3	89.5	180.7	144.3	94.6
D/1	66.3	206.3	49.8	83.3
D/2	30.3	15.2	12.5	19.7
D/3	31.1	16.8	15.5	31.7

= Very Unhealthy, EPA's health alert warning

$PM_{2.5}$ levels during the different periods of the day inside control houses

House/Day	Afternoon	Evening	Night	Morning
Control 1/1	11.7	15.3	7.0	21.7
Control 1/2	25.3	15.3	17.0	15.3
Control 1/3	14.3	8.8	15.8	22.7
Control 2/1	60.3	83.3	120.5	21.0
Control 3/1	68.0	107.2	4.5	92.3
Control 3/2	81.0	195.7*	16.8	45.2
Control 3/3	21.2	35.2	32.2	42.0
Control 4/1	40.0	40.0	17.3	3.8
Control 4/2	16.8	45.0	46.8	6.0
Control 5/1	27.2	3.8	30.4	25.7
Control 6/1	32.7	21.7	4.8	6.5
Control 7/1	34.3	20.2	19.3	19.5
Control 7/2	12.7	4.0	4.7	6.5

* The homeowner burned food while cooking dinner

The chart below shows the hourly averages of $PM_{2.5}$ in *outdoor* air in the vicinity of the control houses, which can be compared to the $PM_{2.5}$ levels in the *indoor* air in the control houses (see bottom chart on page 39).

$PM_{2.5}$ levels in the ambient air in control area

House/Day	Afternoon	Evening	Night	Morning
24 Apr	59	37	42	73
25 Apr	82	34.5	39.0	57.7
26 Apr	52.7	74.7	40.0	40.3
27 Apr	53.5	21.3	19.8	30.7
28 Apr	33.2	38.7	39.2	36.8
29 Apr	17.8	10.8	13.0	9.7
30 Apr.	13.8	26.5	44.3	32.2
1 May	33.3	23.3	25.0	41.2
2 May	43.0	36.7	34.8	51.2
3 May	52.7	55.2	41.5	106.0
4 May	118.0	62.3	60.5	58.7
8 May	40.0	30.2	19.2	16.2
9 May	24.7	48.5	64.7	81.2
10 May	60.0	19.2	12.5	111.5
11 May	9.7	18.5	46.7	25.5
12 May	10.3	16.0	20.3	29.5
13 May	18.2	17.2	21.7	28.7
14 May	34.2	46.8	21.6	25.2
15 May	21.3	15.5	23.7	30.7
16 May	41.0	65.0	65.0	32.8
17 May	13.0	13.7	9.7	7.8
18 May	8.0	15.3	15.7	15.3
19 May	21.2	20.8	26.2	22.2

- ***Comparison of the clinical effects associated with six-hour inhaled dose exposure to $PM_{2.5}$***

The $PM_{2.5}$ particulate counts are viewed as surrogate measures for the presence of wood-burning emissions. Other toxics from wood-burning will also be present inside the houses, including carbon monoxide, oxides of nitrogen, and polyaromatic hydrocarbons (PAHs). These exposures could be included in the differential diagnosis.

At these six-hour average levels, susceptible people with asthma, chronic obstructive pulmonary disease (COPD) or chronic bronchitis may experience clinical effects (see chart on page 38 for the *Unhealthy for All* category). At the *Very Unhealthy* levels on the same chart, everyone may experience chronic bronchitis, and those who are susceptible may require medical support. Those with cardiovascular conditions may experience physiologic effects.

When evaluating health effects in individuals, the actual dose of air pollutants inhaled, including $PM_{2.5}$, is a clear determinant of the clinical response to acute respiratory and cardiovascular toxicants. The findings from the monitoring study permit the determination of actual dose levels for different people.

There are peer-reviewed literature articles that describe the effects of inhalation of increased doses of $PM_{2.5}$, notably a 2006 article published in the journal *Human and Ecological Risk Assessment,* "Assessment of Risk from Particulate Released from Outdoor Wood Boilers."[34] This report, by Brown *et al.,* recommends that the assessment of risks of individual health effects be based on the actual amounts of particulate matter inhaled. A reproducible measure of dose is the mass (micrograms) of particulate inhaled for a specified period of time (six hours or one-quarter of the day). The advantage of such a measure is that it is more directly linked to the target organ for the toxic material, and it incorporates activity differences that influence inhalation of the dose and variability inherent in ambient air measures.

Therefore, we recommend monitoring the hourly air concentrations over a minimum period of 72 hours in order to establish the structure of the exposure patterns. The 72 hours of one-hour monitoring data are divided into 12 units of six-hour intervals. The six-hour inhalation dose is calculated based on the assumption that 0.8 cubic meters of air is inhaled per hour. This can be altered to adjust for greater or lesser activity patterns, such as running or sleeping, and for the ages of the persons exposed. A scale of exposure is suggested in the Brown *et al.* report.

The following six-hour doses* are linked to the following clinical outcomes:

- A dose of 96 ug or more is associated with an **increase in the number of asthma attacks.**
- A dose of 120 ug or more is associated with an **increased need for medical intervention in cases of chronic obstructive pulmonary disease (COPD) in the elderly or asthma in children.**
- A dose of 250 ug or more is associated with **increased emergency room interventions and hospitalizations for ischemic heart attacks.**

Dose risk evaluation for mixtures

Wood smoke emissions are a mixture of gases and particulates. In a local neighborhood setting, a number of other toxic compounds emitted from an outdoor wood furnace would enter the house in the same manner as the fine particulates. Therefore, the presence of particulate in the house is a surrogate measure of certain other toxic compounds from the OWF that would enter the house.

The burning of wood also introduces other toxic materials into the neighborhood. Data from the EPA were used to prepare the chart and graph on the following page, which show the relative concentrations of emission products from outdoor wood burning. Relative amounts of wood smoke emission products are shown in the chart. These graphics demonstrate that substantial amounts of carbon monoxide and other toxics emitted by outdoor wood furnaces, in addition to $PM_{2.5}$, would be expected to enter an OWF-impacted home.

Therefore, any evaluation of the health of persons exposed to wood smoke inside houses in the neighborhood of OWFs must also take into account exposures to all the agents shown by the EPA to be present in wood-fire emissions.

Wood smoke contains unhealthy amounts of particulate matter, as well as a number of unhealthy emissions, including carbon monoxide, volatile organic compounds, benzene, sulfur dioxide, nitrogen dioxide, formaldehyde and several other air pollutants. From the chart, it can be seen that finding $PM_{2.5}$ particulates in indoor air predicts that a number of other toxic compounds will also be present in the indoor air mixture.

*** To obtain the six-hour dose, multiply cts/0.01 ft³ by 2.2**

Relative percentages of toxic emissions predicted to be emitted by OWFs in EPA's Model

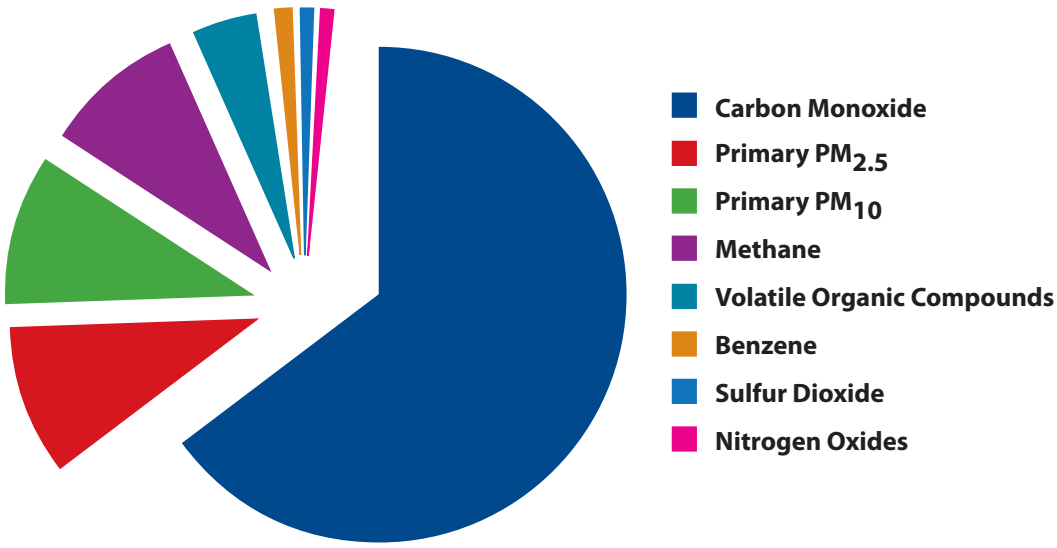


Chart showing relative percentages of toxic emissions predicted by EPA's Model

Carbon Monoxide	64.0249
Primary $PM_{2.5}$	9.6037
Primary PM_{10}	9.6037
Methane	9.0818
Volatile Organic Compounds	4.0711
Benzene	0.9673
Sulfur Dioxide	0.7064
Nitrogen Oxides	0.6263
Ammonia	0.6263
Formaldehyde	0.2436
Acetaldehyde	0.2373
Phenol	0.0839
Naphthalene	0.0517
Cresols (Includes o, m, & p)/Cresylic Acids	0.0456
Acrolein	0.0152
1,3-Butadiene	0.0101
Benzo[a]pyrene	0.0010
Mercury	0.0000
Dioxins/Furans as 2,3,7,8-TCDD TEQs - WHO/98	0.0000

Appendix C.

Findings from the Questionnaire Used in the Study

	House A	House B	House C	House D
Distance to OWF	*850 ft.*	*100 ft.*	*240 ft.*	*120 ft.*
Square footage	*1,664*	*3,000*	*1,300*	—
Floor plan	*Open*	*Small Rooms*	*Open*	*Small Rooms*
# of floors	*2*	*2*	*1*	*2 plus basement*
Style	*Split level*	*Traditional*	*Ranch*	*Traditional*
Attached garage	*Yes*	*Yes*	*No*	*No*
Car in attached garage?	*No*	*Yes, but coasts in*	*N/A*	*N/A*
Working fireplace or woodstove	*1 propane, 1 wood*	*Woodstove*	*No*	*No*
Burns wood?	*No*	*Not during monitoring*	*No*	*No*
Smokers	*No*	*No*	*No*	*1 person, but not in the house*
# of adults	*2*	*2*	*2*	*2*
# of children < age 5	*1*	*0*	*0*	*0*
# of children age 5–12	*0*	*1*	*2*	*2*
# of children 13+	*0*	*1*	*0*	*0*
Pets	*1 dog*	*1 dog*	*No*	*3 cats*
Type of Heat	*Oil, baseboards*	*Oil, radiators, baseboards*	*Electric*	*Oil, forced air*
Type of Hot Water Heat	*Oil*	*Oil*	*Electric*	*Electric*
Cooking Stove	*Electric*	*Gas*	*Electric*	*Electric*
Near Major Road?	*No*	*15 minutes from highway*	*No*	*No, moderate traffic*
How Situated Relative to OWF	*OWF is W, house a bit lower than OWF*	*OWF is N across street, downhill from from house, which has slope behind*	*OWF is NW and downhill from house*	*OWF is NNE and downhill*
Health Effects	*Asthma, sinus infection, ear infection, bronchitis, ongoing cough, child on inhaler*	*Winter sicknesses, "near pneumonia"*	*Decreased lung capacity, increased asthma symptoms, sore throat, dizzy, headaches, vision/ hearing decline*	*Migraines, rash like sunburn, raspy breathing, heart palpitations, son with learning changes*
When Health Problems First Noticed	*Mother, winter 2003–04; child, 1 1/2 years ago*	*Past 3 years, not much this year*	*Over 5 years ago*	*Within last 2 years*

Appendix D.

Planning and Zoning Regulation Used to Ban OWFs in a Town

Below are the zoning regulations from the town of Tolland, Connecticut, which banned outdoor wood furnaces (OWFs), also known as Outdoor Wood Boilers (OWBs). These regulations provide a model for other towns, and planning and zoning commissions that might want to ban outdoor wood furnaces.

ZONING REGULATIONS, TOWN OF TOLLAND
Chapter 170, page 96

CODE of the TOWN OF TOLLAND, STATE OF CONNECTICUT
Zoning Regulations, Rev. July 20, 2009

ARTICLE XIV
Accessory Uses and Structures
Section 170-84. General Requirements.
Accessory uses and structures shall be subject to the following conditions:

A. Establishment of accessory uses.

1. Accessory buildings, structures and uses shall be located on the same lot as the principal building, structure or use to which they are accessory.

2. Accessory buildings, structures and uses shall not be located on a lot without the prior establishment of a permitted principal use, nor shall any new lot be created that has an accessory building, structure or use without a principal use.

B. Prohibited Accessory Uses and Structures.

The Commission feels that, by their very nature, the following uses and structures cannot be regulated in such a fashion as to protect the Health, Safety and Welfare of the general public and are prohibited in all zones.

Outdoor Wood Burning Furnaces, as defined by P.A. 05-227

References

[1] http://www.epa.gov/burnwise/healtheffects.html

[2] http://des.nh.gov/organization/divisions/air/cb/ceps/npsap/smoke.htm

[3] http://www.ct.gov/dep/cwp/view.asp?a=2684&Q=321780

[4] http://www.woodheat.org/technology/outboiler.htm

[5] http://www.ecy.wa.gov/biblio/91br023.html

[6] http://www.ecy.wa.gov/biblio/91br023.html

[7] http://www.epa.gov/burnwise/healtheffects.html

[8] http://www.ct.gov/dep/cwp/view.asp?a=2684&Q=321780

[9] http://www.vtwoodsmoke.org/health.html

[10] http://www.nescaum.org/documents/assessment-of-outdoor-wood-fired-boilers

[11] http://www.spokanecleanair.org/publications.asp (Outdoor Wood-fired Boilers.pdf)

[12] For comparison, fine beach sand is about 90 microns, and the average human hair is 70 microns, in diameter. Thus, particles of 0.1 to 5 microns (very small) are carried in the same way as vapors or gases in the inhaled air stream, reaching the deep and most sensitive areas of the lung.

[13] The United States Environmental Protection Agency (U.S. EPA) has established health-based standards for exposure to particulates in the 10 micron and 2.5 micron range (PM_{10} and $PM_{2.5}$). The standards are used to evaluate the efficiency of air pollution control programs and to warn the public of impending health risk. Background $PM_{2.5}$ 24-hour averages fall between 10 and 15 micrograms per cubic meter (ug/m^3) of air, with high levels reaching 40 to 50 ug/m^3.

[14] http://www.epa.gov/ttnchie1/net/2008inventory.html — the Nonpoint section. Residential Heating: Wood.

[15] Houses that are heated with oil, gas, and coal or wood stoves will draw more air into the house to support the combustion used to heat the house. As warmer air from the stove or furnace exits the house through the chimney, that air is replaced with air drawn from the outside. Thus, greater inflows of outside air increase the rate of contamination in houses with interior stoves and furnaces.

[16] http://des.nh.gov/organization/divisions/air/cb/ceps/npsap/smoke.htm

[17] http://chestjournal.chestpubs.org/content/119/4/1260.full

[18] http://oem.bmj.com/content/65/5/319.abstract

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[19] http://toxsci.oxfordjournals.org/cgi/content/full/65/1/115#SEC3

[20] http://michiganmessenger.com/38678/study-finds-wood-burning-releases-more-greehouse-gas-than-coal

[21] www.swcleanair.org/pdf/WoodSmokeHealthBrochure.pdf

[22] http://www.yakimacleanair.org/woodstove_information.htm

[23] http://www.epa.gov/burnwise/healtheffects.html

[24] http://www.ct.gov/dph/cwp/view.asp?a=3137&q=398480

[25] http://www.hria.org/services/environmental-health/cs-burden-of-asthma.html

[26] http://www.ncbi.nlm.nih.gov/pubmed/11879110

[27] http://oem.bmj.com/content/54/2/108.abstract

[28] http://www.epa.gov/iaq/co.html#Health%20Effects%20Associated%20with%20Carbon%20Monoxide

[29] http://www.health.state.mn.us/divs/eh/indoorair/co/index.html

[30] http://www.merck.com/mmhe/sec24/ch297/ch297d.html

[31] www.epa.gov/airnow/aqi_brochure_08-09.pdf

[32] Zanobetti A, Schwartz J, Gold D. Are there sensitive subgroups for the effects of airborne particles?

[33] http://www.nescaum.org/documents/owbfactsheetfinal.pdf/

[34] Brown, et al. "An Assessment of Risk from Particulate Released from Outdoor Wood Boilers." Human Ecol Risk Assess 13:191-208

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Cover photo: smoke from an outdoor wood furnace near Danielson, Connecticut, by G. Leslie Sweetnam

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Aerial photos of smoke from outdoor wood furnaces in Connecticut on the front cover, page 15 and page 29 were taken by **G. Leslie Sweetnam** (*specializing in aerial art photos of the last green valley, central Massachusetts and northeast Connecticut)*
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