Is This House Sick?

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Introduction

Let’s say you walk into a house where the occupants seem to be sicker than normal. After looking around, you notice some visual clues. You see some condensation and possibly some mold growth occurring at a wall and ceiling intersection.

You also notice some dark markings like soot that appear to be coming out of an outside wall outlet.

The windows are soaked with condensation, and it appears that rot is beginning to occur at the window sills from repeated soaking.

Finally, you check out the heating system in the crawlspace. Upon closer inspection, you can see that the furnace chimney is not connected to the furnace itself.

What is going on in this house. Are these issues related? Are these issues the cause of the occupants being sick. Is this an indoor air quality problem?
Introduction

The goals of this course are to give you a basic understanding of common indoor air quality contaminants that are found in the home, to help you identify indoor air quality issues in the home from either visual clues or other clues, to teach you about common indoor air quality problems that commonly occur in homes, and to determine proper indoor air quality solutions once problems have been identified.

This part of the course is based partially on a study that identified underlying root causes of poor indoor air quality problems in Alaska. One hundred homes were selected for the study in the winter of 2003-2004. This study was funded by Alaska’s Cold Climate Housing Research center, and conducted by Wisdom & Associates, Inc. www.cchrc.org Wisdom and associates studied 100 homes on the Kenai Peninsula in Alaska to find the causes of indoor air quality problems. Indoor air contaminant levels were monitored for a minimum of 48 hours with data loggers that recorded readings every 1.5 to 3 minutes for the entire monitoring period. Some of the issues that were continuously monitored included temperature, relative humidity, carbon monoxide, carbon dioxide, and Radon.

Other issues that were studied included; visible condensation that may have occurred on windows or walls, visible mold growth, sooting or soot markings, heating systems including fuel type, heating appliance category, location, presence of combustion air chimney condition etc., ventilation including the air tightness of the house, whether or not a mechanical ventilation system was in place, whether or not the ventilation met state standards etc., garage type whether attached, detached or tuck under, pressure imbalances within the home and in relation to the outside, and an energy rating was conducted on each home, which rated the energy efficiency of each home on a scale and provided air tightness numbers.

Alaska is an excellent place to study indoor air quality. Alaska has very tightly built homes, and the climate is the most severe in the country. These factors combine to create worst case housing conditions. If homes can survive the cold climate of Alaska the can survive the cold climate anywhere!

Key Points

Some of the key points that were found during the study are good to keep in mind during this presentation. Improper and/or inadequate ventilation were the main culprit causing indoor air quality issues. Many times the ventilation scheme for a particular home would lack adequate supply, adequate exhaust, or would not circulate fresh air where it was needed. Also, pressure imbalance created by a ventilation system often causes problems with heating appliances and soil gasses. Air pressure limitations for combustion appliances were often exceeded with unhealthy results. Proper vapor barriers on the ground were a key factor in reducing moisture and soil gasses in the home. And combustion air was often overlooked. The house is a system, meaning that each component of the home must be treated as part of the whole and that all of its components, including the occupants, must work in tandem to keep indoor air quality problems from developing. If one component is ignored within the home, it does not just affect the one area, it affects the whole house.
Indoor Air Quality

What is indoor air quality? It is the quality of the air that people breathe indoors. When people think of air quality, often the first thing that comes to mind is outdoor air quality. However, indoor air quality can be even more harmful. This is due in part to the fact the EPA estimates that the average person spends 90% of their time indoors. These facts prompted the EPA to list indoor air quality as the 4th largest environmental threat to this country.

Good IAQ

Good indoor air quality consists of a healthy indoor environment that is free from pollutants. Pollutants include unpleasant or noxious odors, dust or other airborne particulates, and/or chemical contaminants. A healthy indoor environment contributes to productivity, comfort, a sense of well being, and healthy occupants.

Poor IAQ

Poor indoor air quality consists of an environment that is not free from pollutants. Occupants in such an environment may suffer from acute health and comfort effects. Building that suffer from poor IAQ may be referred to as having “sick building syndrome”. Poor indoor air quality may originate from one source or many within the building. It is important to remember that the systems within the building are interconnected. A change in one area may have unintended effects in another.

The most common factor that can be used to identify a potential indoor air quality problems is that the health symptoms suffered by the occupants are related to time spent in the building. There are many common health symptoms related to poor indoor air quality, including but not limited to eye, nose and throat irritation, shortness of breath, impaired vision or coordination, digestive problems, allergic reaction, and increased asthmatic episodes. Symptoms also include headaches, dizziness, fatigue, nausea, fever, and frequent colds. Because of the wide variety of symptoms that can accompany an IAQ problem, the single most important factor to consider is that the symptoms get worse with time spent indoors.

Common Pollutants

Some of the common pollutants we will cover are Radon, biological contaminants including mold, combustion air contaminants, carbon monoxide, carbon dioxide, and ultra fine particles.
Radon

Radon is a colorless, odorless, tasteless, radioactive gas which occurs naturally in almost all soils, rocks, and water. It is harmless when dispersed in outdoor air, however, when it is trapped in buildings, it can become harmful. Radon is a by-product that is released from the decay of radium-226. It has numerous different isotopes, but radon-220, and -222 are the most common.

Health Effects

Radon is thought to be responsible for 14,000 to 22,000 deaths per year. Radon is also the second leading cause of lung cancer behind cigarette smoking. Radon gas decays into radioactive particles that can get trapped in your lungs when you breathe. As they break down further, these particles release small bursts of energy. This can damage lung tissue and lead to lung cancer over the course of your lifetime. Not everyone exposed to elevated levels of radon will develop lung cancer. And the amount of time between exposure and the onset of the disease may be many years.

Where Radon Comes From

Since warm air is more buoyant or lighter than cold air, it rises to the upper levels of the structure as this warm buoyant air creates a positive pressure at the top of the structure. If this air is allowed to escape from the structure then is must be replaced since nature hates a pressure imbalance or vacuum. With the warm air rising in the structure a negative air pressure is created at the lower level of the structure. This negative pressure will draw outside air into the structure from any source available. This could include areas of the structure such as cracks in concrete or dirt floors or foundation walls, or openings in the floor around drains, pipes, sumps etc.

Radon Entry

Radon concentration within a home may change rapidly due to several factors, including temperature change. In general, the colder it is outside in relation to inside, the greater the stack effect. The greater the stack effect, the greater the negative pressures at the lowest level of the house where the radon enters the building. Weather changes can also have a dramatic affect on radon levels. High and low pressure weather systems can affect the rate of radon entry into the home. Another key factor that affects radon entry is the use of exhausting equipment such as clothes dryers, range hoods, bath fans etc. Exhausting appliances remove air from the building and create a negative pressure. This negative pressure inside the building can create a vacuum effect on the surrounding soils which in turn can increase radon levels. All of these variables make it critical to measure radon levels for a minimum of 48 hours to determine is levels are safe. Ideally, radon levels should be tested for 90 days to a year to take into account seasonal and occupant use changes.
What areas are likely to contain Radon? We sometimes find elevated levels in pocket areas depending on subsurface soils conditions. In general the more porous soils like gravel and sand are more conducive to allowing radon to pass through them and into the home than a clay type soil that creates an underground cap which can slow Radon entry. However, there are not hard and fast rules for determining if radon issues are likely with a particular home. Testing with an EPA certified device is the only truly accurate way to test for radon.

Reducing Radon

There are several effective methods for reducing radon levels within the home. The first line of defense against radon is the use of well sealed vapor retarders, whether in a crawlspace or under a slab. Plastic sheeting that has been sealed acts as a barrier to the radon and does not allow it to come into the home. For concrete slabs and foundation walls, sealing gaps and cracks is another effective method for reducing radon levels. Sealing gaps and cracks acts as barrier to the radon. Another method for reducing radon levels is to reduce negative pressure in the house. Too much negative pressure caused by exhausting appliances and unbalanced ventilation systems draws radon into the house. If the above method do not work, a sub slab depressurization system can be implemented. This system consists of a gravel sum placed under the floor of the building. A pipe is run from this sump up through the house to the atmosphere. The idea is to collect the radon before it gets into the home and send it outside, bypassing the home. An inline fan can be used to actively suck radon from under the house and send it outside.

Conclusions

In conclusion, radon is a significant indoor air quality problem that is responsible for many deaths each year. There are no visual clues to indicate a Radon problem, Radon must be tested for. Negative pressures inside the home play a large role in creating Radon problems. A well sealed vapor barrier in combination with sealing gaps and cracks in the foundation are effective ways of reducing Radon levels within a home.

**During our Indoor Air Quality study we found that as the negative pressure imbalance of the house with reference to the outside increased, so did the average radon levels in the house. This is because the house is starving for air and bringing it through random cracks in the house floor and crawlspace and/or foundation. As the house draws more air from the outside, it draws more soils gases into the house; therefore we see homes with a high pressure imbalance also have elevated radon levels.**
Biological Contaminants

What are biological contaminants? Biological contaminants are those pollutants which are produced by living things. Most biological contaminants are invisible to the naked eye. Biological contaminants may be generated inside the home or may come into the home from outside. Some sources of biological contaminants include mold, dust mite, pet dander, pests, bacteria and pollen. Remember, any pollutant that is generated by a living organism is considered a biological contaminant.

Biological contaminants are present in every home. It doesn’t matter how often or how well the home is cleaned. Moist biological contaminants are moisture sensitive, which means that excess moisture in the environment will cause them to become worse. Biological contaminants are often airborne and can be spread around the home by air movement through heating and ventilation ducts.

Health Effects
The health effects of biological contaminants vary from person to person. Reactions range from allergic to toxic and infectious. Some common symptoms include water eyes, a runny nose, nasal congestion, coughing, difficulty breathing, headache and fatigue. Some biological contaminants are also known asthma triggers.

Reducing Biological Contaminants
Keeping proper humidity levels is crucial to preventing excessive biological contaminants. Besides keeping the humidity below 50% in the winter, another good rule of thumb can be used for gauging the proper amount of humidity. If condensation if forming on the windows of the home, the humidity level is too high. Because the window is the coldest part of the building assembly, it is the first place condensation will occur. Condensation on windows and window sills is not only a source of moisture for biological contaminants to thrive, it is an indicator that condensation may be occurring in places that are not as visible. Another step to reducing biological contaminants is to eliminate standing water or wet areas in the home. Such areas might include drip pans or at wet basement or crawlspace. Finally, any know triggers that a person may be sensitive to such as pet dander or dust mites can be specifically addressed and steps taken to remove it from the environment.

As this chart shows, humidity has a dramatic effect on biological pollutants within the home. Ideally, humidity in the indoor environment should range from 30% to 50% during the winter months. However, in extreme climates it may be impossible to keep indoor humidity levels above 305 in the winter and under 50% in the summer. The key for keeping biological contaminants in check is to keep humidity levels at 50% or less during the winter months. Humidity levels in excess of 50% during the winter promote condensation and the growth of biological contaminants.
Mold

Mold is a naturally occurring microscopic organism. Mold is found both indoors and outdoors. Mold produces tiny spores that are naturally released into the air. It is there airborne spores which can cause air quality problems. Mold is typically identified as a discoloration of a household surface. Mold comes in a variety of colors including but not limited to white, orange, brown, green and black. Not all mold can be seen. Mold can also be identified as a musty odor.

Mold Growth

For mold growth to occur inside the home, there must be a food source and moisture. Mold can use any cellulose material, including wood, dirt and paper. The paper facing on sheetrock is particularly appealing to mold, and is sometimes called “Purina mold chow” because of it’s ability to grow mold in a short time when wet. Moisture sources within the home can include roof leaks, plumbing leaks, groundwater, or relative humidity levels in excess of 45%. Mold is considered a biological contaminant, which means it can thrive in a high humidity environment. Condensation inside the home is a common moisture source for mold.

Mold growth should be suspected wherever there are visible water stains, moist surfaces, standing water, or any discolored surface where the origin of the discoloration is not known. Old mold growth in a dry area can still pose health risk. Mold in dry areas may be in hibernation, waiting for moisture return. In this state, the spores are still active and can be released into the air if the mold is disturbed.

Health Effects

Like other biological contaminants, there are many physical symptoms to mold exposure that vary from person to person. Medical studies show that mold is an elusive yet importance cause of allergic symptoms. Molds are generally broken down into three categories; allergenic, mycotoxic and pathogenic varieties. Allergenic mold produce sinus problems, cold symptoms, and asthmatic reactions. Mycotoxic type molds can be more severe and issues can include headaches, flu like symptoms, suppressed immune systems and cancer. The pathogenic type molds are known to have adverse health effects to people with suppressed immune systems.

This chart shows how much moisture is released into the air of a home each day by a typical family of four, 5 to 6 gallons of moisture can be released into the air. Combining this moisture with cold household surfaces in the wintertime can be a recipe for condensation and mold growth.
Mold

Conclusions
In conclusion, mold needs moisture to grow inside the home. If the moisture sources are eliminated, the mold growth will also be eliminated. Proper ventilation is crucial to keeping indoor humidity levels below the condensation point on cold surfaces around the home.

This graph shows that 42.5% of homes without a ventilation system, as indicated by the red bar, had mold present on the walls. On the right hand side of the graph we can see that homes with a ventilation system of any type were less likely to have mold.

This graph illustrates that no ventilation system was the least effective way to control mold growth on the window sills versus heat recovery ventilators, which were the most effective. In general, the more advanced the ventilation system type, the more effective it was against combating condensation and thus mold.
Combustion Air Contaminants

Combustion air contaminants is the name given to a wide variety of pollutants that are generated by the fuel burning process. Some combustion air contaminants can be easily identified by sight or smell, these contaminants include nitrogen and sulfur dioxide. Some combustion air contaminants cannot be seen or smelled, including carbon monoxide, carbon dioxide, nitric oxides, ultra fine particles etc.

Sources
Combustion air contaminants can come from any appliance that burns fuel, including furnaces, boilers, water heaters, fireplaces, and cooking stoves. There are many factors that can contribute to combustion air contaminants making their way into the home. The amount and type of ventilation in the home can be a key factor in causing combustion air contamination. Air-tight homes with no ventilation or an exhaust only ventilation system are candidates for combustion air problems because of the negative air pressures that can be created. Also, the condition and installation of chimneys and vents are critical to preventing problems. Improper chimney slope, loose connectors and horizontal runs that are too long can allow combustion air contaminants into the home. Some visual indicators that can be seen at the appliance itself are black soot stains on the chimneys, vents or around the burners or a yellow natural gas flame. Soot stains on or around the appliance indicate that combustion products are not exiting the home properly. A yellow natural gas flame indicates that the appliance is not tuned correctly and will produce excessive contaminants.

Other identifying marks of combustion air contaminants include visible leaking smoke or gases from combustion appliances, or pungent or smoky aroma that may smell faintly of the fuel type being burned. It is important to remember that some types of combustion air contaminants are impossible to detect by sight or smell, and Store bought tests are not always sensitive enough to detect a problem. Many types of combustion air contaminants cannot be tested for with home test kits.

Health Effects
The health effects of combustion air contaminants are very dangerous. The nitrogen and sulphur dioxides can cause respiratory irritation, infection, and even pneumonia. Carbon monoxide, which is also known as the silent killer, will produce cold or flu like symptoms, as well as headaches and fatigues. High levels will cause coma and death. Carbon monoxide is particularly dangerous because it accumulates in the blood over time. Carbon monoxide will be explored in depth in the next section. Ultra fine particles are another combustion air contaminant that can cause a wide variety of health problems, either from the chemical make up of the particles or from the sheer volume inhaled. Ultra fine particles refers to a wide array or tiny airborne particles that can be inhaled, and in the case of combustion air contaminants they refer mostly to soot particles.
Carbon Monoxide

Carbon monoxide is a combustion air contaminant that is colorless, odorless and tasteless. Carbon monoxide is a by product of the fuel burning process. Carbon monoxide is unique from other combustion air contaminants in that it accumulates in the blood stream over time. Small doses of carbon monoxide at levels not normally registered on household CO detectors on a regular basis can cause chronic health problems.

Health Effects
The health risks associated with carbon monoxide get progressively worse as levels increase. Zero parts per million is the desired level in all situations. Up to 9 parts per million is considered an acceptable level, although even these levels can causes chronic poisoning. Any levels over 50 parts per million are not acceptable, and levels above 400 parts per million become seriously life threatening.

Carbon monoxide has a half life of 5 hours, which means is a person received a dose of 8 parts per million of carbon monoxide right now, in five house that person would still have 4 parts per million in their blood stream. Persons spending large amounts of time in the presence of low levels of carbon monoxide may not be able to clear the CO from their bloodstream and will suffer adverse health effects.

Sources
Carbon monoxide comes from any fuel burning process including any un-vented or improperly vented gas, diesel, or kerosene room heaters, fireplaces, water heaters, vehicles, furnaces, boiler and space heaters.

This graph shows that homes with cooking stoves that utilized natural gas or propane instead of electricity had nearly double the average carbon monoxide level.

This graph shows the average carbon monoxide level in the homes versus the fuel type. Natural gas and propane were significantly higher than electricity and oil. Oil hot fired domestic water heater had lower CO levels because most oil fired appliances are category II force or induce draft.
Carbon Dioxide

Carbon dioxide is also a colorless, odorless and tasteless gas, although the health effects are not as severe as carbon monoxide. Carbon dioxide is a byproduct of occupant respiration, meaning every time a person exhales, they are exhaling some carbon dioxide. Carbon dioxide also comes from the combustion process, including heating and cooking.

Health Effects

The American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE) has set an exposure limit for carbon dioxide in the Standard 62. That limit is 1000 parts per million for continuous exposure. This is the uppermost limit, and many public buildings such as schools strive for levels below 700-800 parts per million. Carbon dioxide levels are a good indicator of overall indoor air quality, since they reflect the amount of activity taking place in an area. High carbon dioxide levels usually point towards high levels of other pollutants and a need for additional ventilation to the space. Excessive carbon dioxide levels produce symptoms including stiffness, drowsiness, stuffiness and lack of energy in those who are exposed.

This graph shows an overall trend of carbon dioxide levels increasing as the number of occupants increases. The more people that are present in the home, the more carbon dioxide is produced and the more important proper ventilation becomes.
Ultrafine Particles

Ultrafine particles is the name given to any airborne particle that causes health problems when inhaled. Specifically, a particle is considered ultra fine when it is smaller than 30 microns. To give an idea of size of 30 microns, it takes 25,000 microns to make one inch, and the very finest human hair is about 30 microns in diameter. 99% of particles suspended in indoor air are too small to see. One cubic foot of air may contain as much as 400 million unseen particles, the majority of which will be much smaller than 30 microns.

Particle Types

There are many different types of ultrafine particles, including chemicals which are usually the products of combustion or chemical reactions occurring at a wide variety of sources. Dust which enters the home through normal air infiltration or by being tracked into the home then ground up by repeated foot traffic until it is of small enough size to stay suspended in the air. Some dust is generated from other products such as asbestos which can be as small as 0.3 microns. Biological contaminants may also may enter the house from outside air or may be generated inside the home in high humidity areas including bathrooms and crawlspaces. Bacteria and viruses also fall under the category of ultrafine particles. They may be present inside the home under normal conditions. Viruses (.003 to .05 microns) are much smaller than bacteria (.3 to 30 microns) but both will “piggyback” on larger particles of dust. Lint, which encompasses carpet and clothing fibers, as well as cat, dog, and human hair. Finally, combustion air contaminants and smoke may contain ultrafine particles. These ultrafine particles are produced by smoking, burning candles, cooking, and from the biggest producer, combustion appliances. Smoke particles entering your home through stoves, chimneys, and vents are not always visible to the naked eye.

Health Effects

The health effects related to ultrafine particles are often difficult to pinpoint because of the wide variety ultrafine particle composition. However, identifying what a particle is made of is not as important as finding where the particles are coming from, then eliminating the source. The chemical makeup or the sheer volume of particles can trigger a health response.
Identifying Visual Clues - Condensation

Many times when investigating a possible indoor air quality problem, the occupants have no idea that it is the air inside their home that is making them sick. During an investigation, we often rely on visual clues to give us an idea of potential issues that are causing indoor air quality problems.

Condensation
Condensation is an excellent indicator that the indoor air quality in the home is poor. Condensation occurs when moisture vapor in the air comes in contact with cold surfaces in the home like windows or un-insulated portions of the wall. Condensation occurring in the home is usually a sign of a buildup of moisture which can foster biological contaminant growth, as well as other pollutants which may not be visually identifiable. Many household activities can contribute to excessive moisture and condensation, including showering and bathing, washing dishes, laundry and breathing.

Relative Humidity
Relative Humidity (RH) is the amount of moisture in the air relative to the amount of moisture the air could hold if the air was saturated. The saturation point changes with the temperature because warm air will hold more moisture than cold air. Relative humidity is described as a percentage. As we noted earlier, the moisture itself is not harmful, but it may create conditions which promote the growth of biological contaminants. Condensation occurs when the relative humidity in the home reaches 100%.

Another way of saying this is that condensation occurs when the indoor air temperature cools to the point that it can no longer hold water vapor and liquid water forms. Excessive humidity combined with cold surfaces inside the home creates condensation.

Ideally, the relative humidity in the home will stay between 35% and 45% in the winter months. Levels below 45% will prevent condensation from forming on cold surfaces inside the home on all but the coldest days. More than 45% relative promotes condensation in the home and will allow biological contaminants to thrive.
Identifying Visual Clues - Condensation

When looking for issues in the home, condensation can easily be identified on windows. Windows are the best place to look for condensation in the home because they are typically the coldest surface.

This photo shows heavy condensation buildup on a window in the winter time.

This photo shows where condensation had occurred on the window on a regular basis during the winter. Note the water stains and the paper towel which is stuck to the window sill where the occupants had tried to mop the moisture up.

This photo shows an extremely severe case of high humidity and condensation inside the home. Water was building up on the window sill and draining to the exterior, where it froze on the side of the building.
Identifying Visual Clues - Sooting

Sooting is another common visual indicator of indoor quality problems, although sooting is not a problem by itself. Sooting is a symptom of other problems occurring in the home. Commonly, sooting indicates that a fuel burning appliance in the home is backdrafting. Although soot may also come from smoking, heavy candle use or wood burning appliances.

Sooting occurs when conductive heat loss at wood joints in the home creates a cool surface. The dew point, or the temperature at which moisture in the air turns to liquid, is lower in these areas than at the insulated portions of the wall. This microscopic moisture acts like a magnet to ultrafine particles like dust or soot.

Wood is a much more efficient conductor of cold than insulation. The wood studs on this wall have an R-value of about 6.25, compared to the insulated bays of this wall, which have an R-value of about 22. The stud areas will be considerably cooler than the insulated areas, making those areas the first place for microscopic condensation to occur. Truss/wall connections are another cold spot because of the lack of insulation in these areas.
Identifying Visual Clues - Sooting

Sooting can be seen above this outlet where cold air from outside was being pulled into the house due to negative pressures. The same negative pressures that were pulling the cold air in were also causing the heating appliance to backdraft, resulting in the soot markings.

Soot markings can be seen here at the intersection of the trusses and the wall, where a cold spot occurred because of a lack of insulation.

This photo shows soot markings outlining the rafters. If there is 10 inches of insulation in this attic, there is only 4 inches of insulation covering the top of the rafters, making those surfaces of the ceiling cooler.
Identifying Visual Clues - Sooting

Sooting & Heating Appliances
If combustion appliances in the home are the source of soot markings, there is a serious indoor air quality problem. Sooting from combustion appliances means that those appliances are backdrafting and spilling combustion air contaminants into the living space. Combustion appliances are subject to maximum negative pressure limitations. When those limitations are exceeded, the appliance will backdraft.

Heating appliances are broken down into three basic categories of appliance:

A category I appliance has a natural draft exhaust system in other words it relies on the buoyancy of the hot air in the chimney to remove the combustion gasses up the chimney.

Category II appliances are typically more efficient thus they have a lower stack temperature and need a fan to assist in the removal of the combustion gasses. These are sometimes referred to as induced or forced draft appliances.

Category III appliances are the most efficient of the appliances and thus have to lowest stack temperature and also require a fan to assist the removal of the combustion gasses. This type of appliance has a sealed combustion chamber that takes its combustion directly from the outdoors and does not rely on indoor air for the combustion process.

Each category of appliance has a maximum limit of negative pressure allowed by the BEES standard with in the house. When these limits are exceeded the appliance can be back drafted, spilling combustion gas products into the house. Category I / Natural draft appliances the limit is 5 Pascal's. Category II or Induced or forced draft appliances the limit is 10 Pascal's. Category III sealed combustion appliances the pressure limit is 20 Pascal's.

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Negative Pressures and Backdrafting

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<td>Category III</td>
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Identifying Visual Clues - Sooting

This graph shows that only homes with natural gas as the heating fuel type had soot markings present on the walls. This suggests that natural gas appliances may backdraft more easily than oil fired because of lower stack temperatures and the fact that most oil fired appliances are induced or forced draft and many natural gas appliances, especially water heaters, are natural draft.

Sooting Present in Garage

This graph shows that percentage wise twice as many homes with a category 1 combustion appliance had sooting present in the garage than did homes with category 2 or 3 combustion appliances. This suggests that category 1 heating appliances backdraft more easily than category 2 or 3 appliances.
Identifying Visual Clues - Sooting

This graph shows that only homes with a combustion category 1 hot water heating appliance had sooting present in the garage.

This graph shows the average carbon monoxide level in the living space versus whether or not sooting was present in the living space. The average carbon monoxide levels was more than twice as high when sooting was present in the living space.
In conclusion, soot markings inside the home are a valuable indicator of indoor air quality problems. Sooting points to backdrafting of combustion appliances and increased carbon monoxide and other combustion air contaminant levels. Category 1 natural gas hot water heaters are very sensitive to negative pressures inside the home, and if they are present many times they are the cause of sooting.

This graph shows that houses where the combustion appliance back drafted under worst case negative pressures in the house were twice as likely to have sooting present in the garage. This finding established a statistically significant link between soot
Identifying Other Clues - Pressure Imbalances

There are other important clues to look for during a sick house investigation that may not be visible or readily apparent. These clues may require gauges and instruments to measure.

**Pressure Imbalances**
Pressure imbalance are the differences in pressure between different areas of the house. Pressure imbalances can be tested for by running special hoses to the major areas of the house such as inside, outside, the garage, mechanical room and crawlspace, if applicable. Hoses from each area of the house are run to a maneghelic gauge and readings area recorded in Pascals of pressure difference between the areas.

Then the combustion appliance with the weakest category rating was caused to fire. For example, if a house had a category 1 hot water heater and a category 2 boiler, the hot water heater was made to fire because it is the most sensitive to negative pressures. Then to see if the combustion appliance was backdrafting, recordings were taken with the ultrafine particle counter and recorded.

Two criteria were set to determine if a combustion appliance was backdrafting. First, a jump in particle count of at least twice the number previously noted during the initial ultrafine particle sweep was recorded during backdraft testing, the appliance was considered to be backdrafting. Second, if there was an increase of 2000 particles per cubic centimeter or greater during backdraft testing, the appliance was considered to be backdrafting. Two criteria were set because of the range of initial particle readings before the backdraft testing was conducted. Initial readings ranged from 500 particles per cubic centimeter to over 100,000 particles per cubic centimeter.

**Backdraft Testing**
Wisdom & Associates performed backdraft testing on all homes during our indoor air quality study. This was accomplished by turning on all exhausting and ventilating fans in the house at once.

This illustration shows how pressure imbalances between different areas of the house are measured. For example, excessive negative pressures caused by exhaust fans may result in pollutants being drawn in from the garage.
Identifying Other Clues - Pressure Imbalances

This graph shows that a homes where the negative pressures exceeded the combustion category rating of the appliance, the appliance was much more likely to backdraft. Also of interesting note, over 40% of homes that did not exceed negative pressure rating of the weakest combustion appliance still had backdrafting issues. Many appliances will backdraft before their maximum negative pressure limitation is reached due to design, installation and maintenance issues.

This graph shows that over 40% of homes with natural gas fired appliances had backdrafting problems compared to less than 20% of homes with oil fired appliances.
Conclusions
To understand what the typical home goes through in terms of negative pressure imbalances, we ran the numbers and found that the average maximum depressurization of all homes in relation to any other part of the home was -9.0 Pascals. The average maximum depressurization of the largest 3 fans in all homes in relation to any other part of the home was -8.2 Pascals. Average total depressurization between the home and the outside was -8.3 Pascals. This means that the average home exceeds the combustion category 1 negative pressure limitation automatically.

This graph shows that homes without combustion air for the heating appliances were more likely to have backdrafting problems than homes with combustion air. Interestingly, over 10% of homes with category 3 heating appliances that did not require combustion air still backdrafted during pressure imbalance testing. This is also due to installation and maintenance issues.

The average total depressurization between the home and a garage was -5.2 Pascals. This means that any pollutants generated inside the garage are being pulled into the living space. Also, any category 1 combustion appliances are probably subject to backdrafting as well. The average total depressurization between the home and a crawlspace was -3.2 Pascals. Again, any pollutants, including radon, are pulled up from a crawlspace into the home.

More than 50% of the homes with a category 1 hot water heating appliance suffered backdrafting during pressure imbalance testing. Typically, category 1 or natural draft hot water heaters are the most sensitive to negative pressure imbalances and have been the most problematic appliance we have dealt with in an indoor air quality setting.
Garages

Garages can be the cause of many indoor air quality problems. Cars are a large source of carbon monoxide. Also, any fuel, paint or cleaning agents present in the garage can generate pollutants which make their way into the house. There is a well established link between pollutants in the garage making their way into the home.

In this graph the black line is carbon monoxide level in the garage, and the blue line is the carbon monoxide level in the home. Spikes in the garage carbon monoxide level correspond with times the car was pulled in or out of the garage. Levels reached over 120 parts per million in the garage. Smaller spikes of carbon monoxide occurred in the house immediately after they occurred in the garage, showing the communication between the two areas. A person spending a lot of time in the house would be subject to low level carbon monoxide poisoning.

This graph shows numerous carbon monoxide spikes in the garage, followed by numerous carbon monoxide spikes in the home. The periodic spikes in the garage resulted in a 4 parts per million average in the living space.
When looking at indoor air quality issues, the most important thing to remember is that the house is a system. Components within the home may interact in unexpected ways. The goal of an indoor air quality investigation is to find the root cause of the issue rather than to just treat the symptoms.

For example, if a home had mold growing in it, there is an indoor air quality problem. However, just cleaning up the mold doing nothing else will not solve the problem. In order to truly resolve the issue, the mold needs cleaned and the source of moisture that is causing the mold growth eliminated.

Another instance of finding the root cause is condensation. If heavy condensation is occurring on the windows of a home, just mopping up the condensation is only treating the symptom, not fixing the problem. A better route to take would be to identify where the moisture that is causing the condensation is coming from, and formulating a strategy to eliminate the moisture source. An couple of possible solutions would be increasing the ventilation in the home and/or getting rid of any standing water or leaks in the house.

If it was decided that ventilation was the way to reduce condensation in this case, we have to be certain that the additional ventilation is carried out properly. Simply installing a large exhaust fan in the house with no fresh air makeup has a domino affect on other systems in the house. A large exhaust may solve the condensation issue, but is will also create negative pressures which can cause backdrafting of combustion appliances and the drawing in of Radon and other soil gasses.

When diagnosing an indoor air quality problem, it is important to take into account how any possible solutions to the issue may ultimately have a negative effect somewhere else in the house.

**Conclusions**

Every indoor air quality problem is different. However, there are some general patterns that most houses follow in terms of problems and solutions. The following observations should be kept in mind when dealing with indoor air quality problems.

**Combustion Air**

We find that a common problem with many homes is lack of or inadequate combustion air for the heating and how water systems. This is especially important for today's newer and the more airtight homes. People are often reluctant to cut a 6 or 8 inch hole in the wall to allow air for their appliances to operate properly, but not doing so can have bad consequences. Code prescribed amounts of openings to the outside should be installed in the same area as the combustion appliances.
Indoor Air Quality - Conclusions

Negative Pressure
Another common issue that is related to combustion air is negative pressures inside the home. Excessive negative pressures cause heating appliances to backdraft and soil gasses to be pulled into the home. At a minimum, negative pressures in the home should not exceed the combustion appliance category of the weakest combustion appliance in the home. As we have seen, some appliances will backdraft at negative pressure levels which are below their category rating. In instances where negative pressure limits are exceeded, relief air openings in addition to combustion air should be installed in the home to keep negative pressures at safe levels.

Ventilation
Proper ventilation of the home is also critical for avoiding and or treating indoor air quality issues. Proper ventilation removes pollutants from the house prevents a buildup of moisture. Proper ventilation consists of a few basic principals. Ventilation to the home should meet minimum flow requirements for the state or jurisdiction in which the home is located. Ideally, ventilation capacity will be above minimum requirements should acute indoor air quality issue arise. Ventilation air should be circulated into and out of all habitable rooms, and should not cause human discomfort. The ventilating system should not cause drafts or be obnoxiously loud, those kind of systems usually get short circuited by the occupants. Finally, the ventilation system should not cause excessive negative or positive pressures. A heat recovery ventilator is ideal because both the supply and exhaust air flows can be adjusted and balanced. Exhaust only ventilation systems, which rely on negative pressure to draw fresh air into the house, are more common in retrofit situations.

Special attention must be paid to prevent too much negative pressure.

Vapor Barriers
A well sealed vapor barrier on the ground level of the home, whether in a crawlspace or under a slab, is key to reducing moisture and Radon levels in the home. A continuous plastic sheet acts as a barricade to moisture that comes up from the ground and to soil gasses.

Natural Gas
It has been out experience that natural gas fired appliances are more sensitive to negative pressures in the home that other fuel types, especially natural gas water heaters. Standard tank natural gas water heaters are rated to -5 Pascals of pressure, but often they will backdraft at lower levels. Best practice installation of these appliances is critical to avoiding potential indoor air quality problems. Cooking stoves are also a source of pollutants inside the home that can contribute to indoor air quality issues. Gas fired cook tops produce carbon monoxide, carbon dioxide and moisture when they operate. Avoiding recirculating range hoods if at all possible and educating the occupants of the home on why it is a good idea to use the range fan whenever cooking is a step towards improving indoor air quality. These are just a few of the recurring problems that cause indoor air quality issues in the home. Now let’s take a look at some real sick house case studies.

Natural gas standard tank water heaters can spell trouble for indoor air quality if not installed and maintained correctly.