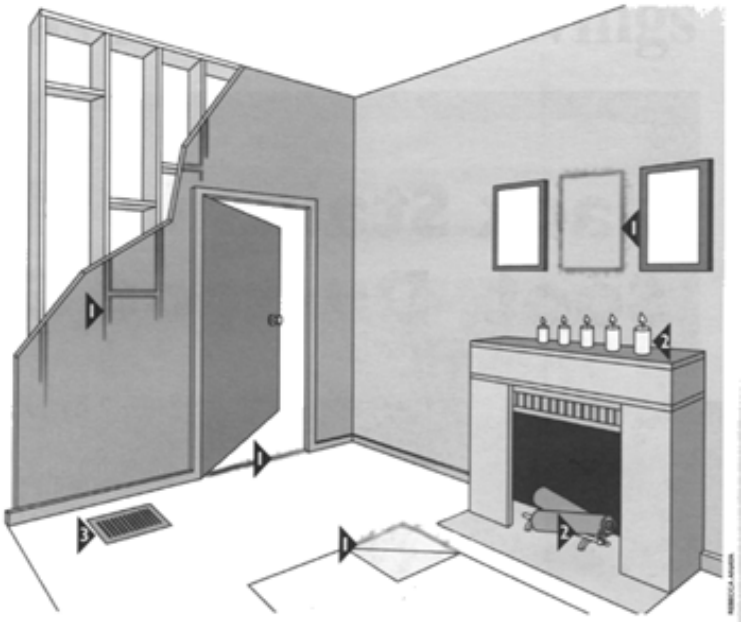
# Black Stains in Houses: Soot, Dust, or Ghosts?

**by Frank Vigil**

**Builders are never more surprised than when they walk into one of their newly built model homes and find black stains at wall-to-floor joints and on previously pristine carpeting underneath doorways. What causes these stains and how can builders and homeowners prevent them?**

**Aromatic candles in this designer bathroom might look elegant, but because they contain a high concentration of oils, they are causing soot deposition throughout the home.**



By now, we've all heard about "black soot" or "ghosting"--one of the hottest topics in the building industry today. The dark marks have been seen on interior and exterior wall surfaces; on carpet surfaces at wall-to-floor connections or door undercuts; on ceilings; on furniture, heating and air conditioning filters, blinds, drapes, doors, countertops, television screens and computer monitors; and on the top side and leading edges of ceiling fans.

The most recent and increasingly common form of staining is caused not by dirt or dust but by soot (see "Dirt and Dust Also Cause Ghosting Stains"). Ghosting from soot is seen primarily in more recent construction, but diagnosticians have detected soot stains in older residences as well. Typically, newer homes--often still under warranty--are the focus of attention. There have even been reports of the problem in newly built, still unoccupied, model homes. Unfortunately, there are as many opinions about the causes of ghosting as there are occurrences of the mystery.

The black soot will outline items, such as ornaments and pictures hanging on walls. Some of the substances seem to have a particular affinity for plastics, such as coffeemakers, blenders, or garbage cans. Deposits have also frequently been observed along the traceline between carpeted flooring and the edge of draperies, vertical blinds and

**Figure 1. Ghosting stains have been seen on interior and exterior wall surfaces; on carpet surfaces at wall-to-floor connections or door undercuts; on ceilings; on furniture, around wall and floor coverings, and numerous other places (1). For a stain to appear, two factors must be present. There must be a source of particulate matter, like the carbon soot from candles or gas log fireplaces (2) and there must be a driving force, like gravity, electric attraction, or a forced air unit (3) to push the particulate against a surface.**

**Gas log fireplaces like this one are a common source of soot in homes with ghosting problems.**

## Dirt and Dust Also Cause Ghosting Stains

Although this article focuses primarily on soot staining, it's important to point out that other pollutants can cause streaks or marks to appear. To the untrained eye, these could be mistaken for soot staining, when in reality, they are caused by impaction from dirt and dust. Such marks are quite common under interior door undercuts, where the door is often kept closed. Positive pressure in the closed room, caused by supply registers blowing air into the room, forces the air to pass through the largest available hole. In this case, it's typically the door undercut. As the air passes between the door undercut and the carpeting, the carpet serves as a filter, "cleaning" the air of particulate such as dirt and dust. Over a period of time, the carpet begins to darken as more of the dirt builds up.

Negative and positive pressures in a building can also create stains. Air, entering the building through holes and cracks, will leave dirt and dust on walls where there is exfiltration and on the insulation that covers those leaks. In a building exposed to pressures from high stack effect (warm air rising) or mechanical pressures (such as those from duct leakage or exhaust fans), staining can sometimes occur at the carpet edge where the interior or exterior wall joins the carpet. Again, air is looking for a hole to exit. When a wall is open to an attic, the air will find that hole and the carpet will filter the air as it passes

bed ruffles--even on the inside of refrigerators! The marks may be random smears or they may form clear geometric patterns, following the lines of the framing behind the surface. The marks range in size from small and isolated spots to soot running along the entire height of a wall.

Although there have been isolated occurrences during the past decade, reports of this problem have increased significantly during the past few years. However, no conclusive causes or solutions have been determined.

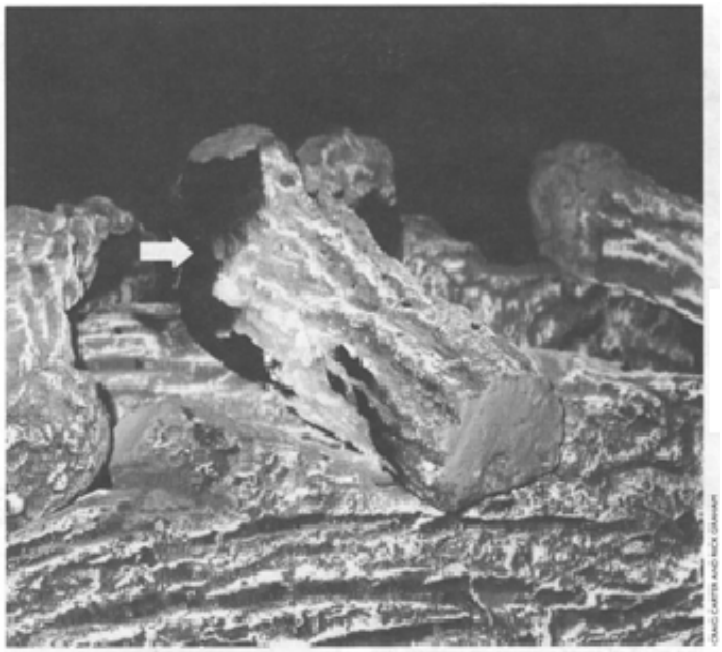
Observers typically claim that the deposits are a result of (depending upon geographic location) fireplace problems or mold caused by condensation on cold surfaces. Few builders understand house-as-a-system interactions, and most seek a single source to blame for the problem. In fact, there are always two culprits at fault. Any time deposition of soot, dust, or carbon appears, first there must be a source of the material, and second, there must be a driving force to cause the material to deposit itself on a surface.

### Sources of the Soot

Investigations in buildings across the nation reveal multiple sources of the stains. Lab analyses indicate ingredients ranging from carbon soot (that might come from fireplaces, water heaters, furnaces, standing pilot lights, candles, cigarette smoke, cooking byproducts, and even automobile exhaust) to other ingredients such as paraffin, benzene, toluene, silicates, iron oxide, cellulose and cotton, dirt or clay, pollen and carbonates (typically found in airborne dust), common grease, and nicotine. One lab even reported that these black deposits "could be the result of carbon from automobile tires which becomes airborne as tires become road-worn" (although the authors were unable to substantiate this

through.

It is also common for random stains to appear on exterior wall surfaces. These stains will take on geometric shapes, matching the framing behind the Sheetrock. This type of staining is often the result of thermal bypasses due to poor insulation practices. Air moves in and around the insulation, often along framing members, and cools the surface of the Sheetrock. On the inside of the house, this cooler surface then offers a more attractive environment for airborne dirt and dust.



**The pilot light from the gas log is "impinging" or touching the log itself, causing soot to form on the cooler surface of the log. The soot is then dispersed through the house with help from the air handler and stack effect.**

**The skirt of the sofa acts as a collection device for the soot in the air caused by the gas log. Note the ring of soot deposited around the bottom of the skirt.**

information). Occasionally, tests do indicate mold spores and/or mildew, but these are easily identified and should not be confused with the increasingly more common forms of black stains that are cropping up.

Carbon molecules act in ways that can make precise identification difficult. Although the black color often leads to the assumption that the sole ingredient of the material is from a combustion-related source, we have learned that this is not always the case.

Hydrocarbon compounds will seek equilibrium with the surrounding environment (Frick's law). That is, they will absorb whatever is in the surrounding air. As the concentration of pollutants increases or decreases, the concentration in the carbon molecules will change. The length of time required for this to occur depends on many different factors, ranging from ambient temperature and molecular weight of the particles to the polarity of the compounds involved. Although laboratory analysis can tell us if the sample contains carbon soot commonly found from incomplete combustion, it cannot positively identify the actual source of the material.

## Driving Forces

Once the sources are identified, a diagnostician must determine what driving forces are responsible for depositing the material. This often requires some real detective work.

There are three known forces at work that can be responsible for the deposits. They are impaction (forced air), gravity, and attraction (electrostatic forces and moisture). The location of the deposits gives a good indication of which of the three forces may be responsible.

### Impaction

**When a room is pressurized, air leaves through the holes in the structure--in this case, along the baseboard at the wall-to-floor joint. As soot particulates in the air exfiltrate through that joint, the carpeting acts as a filter.**

**An example of impaction. Supply air registers located inside this bedroom pressurize the room. The air in the positively pressurized bedroom seeks the path of least resistance toward the lower pressure of the main body of the house, where the cold-air return is located. Air passes underneath the closed door, causing the carpet to act as a filter for particles. Over a period of time, the carpeting will pick up enough airborne particles to cause the discoloration.**

**An aromatic candle in a jar is the only candle in this northern Virginia home. Note the black soot coating the top half of the jar. Even though the homeowner claims that she runs the kitchen exhaust fan when the candle is lit, the candle has managed to cause soot stains around pictures on the wall and along wall-to-ceiling joints throughout the entire one-story house. In some cases, running air turbulence across a lit candle can cause it to soot even more.**

Dark stains on carpet underneath a bedroom door, for example, are an indication that the door is probably often closed. Supply air coming from registers located inside the bedroom pressurizes the room. Air in high-pressure areas like the newly pressurized bedroom automatically seeks low-pressure areas. So the air in the positively pressurized bedroom will seek the path of least resistance toward the lowest pressure. This "lowest pressure area" would be the main body of the house where the cold air return is located. Air passes underneath the closed door, causing the carpet to act as a filter for the air. Over time, the carpeting will pick up enough airborne particles to cause the discoloration. This phenomenon--probably one of the more common ones observed--is an example of impaction or forced air.

**Gravity**

Gravity is usually far easier to establish than the other two types of driving forces. Thanks to a study by John Spengler of the Harvard School of Public Health, we know how long particles of different sizes can remain airborne. According to Spengler, human hair, skin flakes, observable dust in air, and common pollens, all ranging in diameter from less than 10 microns (dust) to 150 microns (human hair), require approximately five seconds to settle 1 m (3.2 ft). Mite allergens, common spores, and bacteria, ranging in size from 1 micron (bacteria) to 20 microns (common spores) require five minutes to settle 1 m. Particles such as cat dander, tobacco smoke, metal and organic fumes, and cell debris, all ranging in size from 0.01 microns (cell debris) to 0.9 microns (cat dander), require a full ten hours to settle 1 m. On the far side, viruses, smaller than 0.01 micron, will remain airborne for as long as 10 days before settling 1 m. Soot, which is carbon black particulate, ranges in size from 0.03 to 3 microns, and can remain airborne for prolonged periods of time before settling.

Thanks to gravity, all debris eventually settles (assuming there's no wind, stack air, or forced air to keep it airborne). Settled particles tend to cover most flat surfaces in a house in a rather uniform manner. However, other driving forces, such as impaction (forced air) might be at work as well, bringing the particles into the building where gravity then begins its work. For example, a duct system, with a leaky return located in the garage, will act like a household vacuum, sucking up auto exhaust fumes and other airborne contaminants floating about. The house, unfortunately, becomes the vacuum bag, and is the repository for everything sucked in by the return. And guess who lives inside the vacuum bag, serving as the final filtering system? You.

Even if return ducts are tight or are not located in the garage, leaky supply ducts located anywhere outside the heated space can make the house have a negative pressure with respect to the outside. This negative pressure then causes outside air, along with whatever is in that air to enter the house through cracks, crevices, and holes. Once inside, the particulate in the air will either randomly settle on various flat surfaces (gravity) or follow the airstream until it strikes a solid surface (impaction). Leaky interior walls, open to the attic, may show discoloration at the wall-to-floor connection where carpeting has been filtering the air as it passes up into the wall.

**Attraction**

Recent research by J. David Krause of Pure Air Control Services and Kaiss K. Al-Ahmady at the Florida Department of Health, Bureau of Environmental Toxicology, has focused on how particles, when properly charged, will coat a surface that has an opposite charge.

Air coming out of the air handler (central heating/air conditioning system) at a high enough velocity, and then passing through a lined duct system, such as duct board, can become electrically charged. The ACCA's *Manual D* for residential duct systems, suggests a velocity of between 600 and 900 feet per minute (FPM) for trunk ducts (as opposed to duct branches), depending on the type of duct system (rigid or flex) and whether it is the supply side or the return side. Measured velocity in many of the houses with soot deposition problems has been as high as 4,000 FPM, with typical numbers in the 1,500-2,000 FPM range. Also, the relative humidity in these houses has been lower than 55%, and there is a source of carbon soot (if nothing else, at least a candle burning).

This charge is then passed on to any particles moving through the airstream. In a duct system that has both high velocity and some portion of the system lined with fiberglass, two kinds of charging can occur. First, particles that are simply passed along the fiberglass surface at high speed may receive a unipolar charge. Once charged, the particles will be naturally attracted to any surface in the home that has the opposite charge. The second charging condition is called bipolar; it occurs when the particulate is caught in some air turbulence within the duct system. Due to the complex electrical process that this situation causes, the particles have both a positive and a negative charge. Thus, the particles are now attracted to each other, and collect to form larger, more visible particles. This substance will then either attach itself to a charged surface in the house, settle onto a flat surface, or deposit as a result of impaction--on fan blades, for example, or on the filter media for the air handler.

## Not-So-Mysterious Ghostly Marks

Researchers have observed that staining happens more frequently during the winter months, but it also occurs during summer months when interior relative humidity is below 50%. The source for the soot varies. Soot staining has been found in houses where owners didn't burn candles and the only source of combustion was a standing pilot light in a gas

log fireplace. Other examples include homes where gas log fireplace logs were adjusted (more were added), causing increased interference with the flames and resulting in significantly large quantities of carbon soot production. The house was literally coated with soot stains.

One homeowner in Texas has been frequently burning up to 10 candles at a time for more than 12 years in the same house with no problems--until now. Last year, she went to a well-known clothing store that also carries various decorator items. The store was promoting a very soft, aromatic wax candle. The homeowner replaced all of her existing candles with these new ones, and that's when the problems started. Stains began to appear after several months. Soon, stains appeared on walls, windows, fabrics (drapes, upholstery, clothing, etc.), and electronic equipment. Within a few more months, the stains were obvious on most everything else in the house, including plastic items, electrical outlets, light and fan fixtures and even in the refrigerator. This is a classic case of soot plating caused by candles. Laboratory tests of the candles indicated that they produced exceptionally high levels of soot (some candles burn dirtier than others). (Because of ongoing litigation, further information about this situation is being kept under wraps.)

Another homeowner was fanatical about cleaning her house. When she began to find dust stains, she thought she must have been doing a poor job of vacuuming. When she finally called us at Advanced Energy for an analysis, we discovered that her vacuum cleaner was the actual source of the problem! Vacuums often leak more dust back to the house than they remove.

In another case, Advanced Energy was called to investigate a problem house where all of the carpeting had been replaced twice, as a result of "mysterious black lines that appear every 4 ft on our upstairs carpeting." Diagnostics, including pressure mapping of the house, revealed the source of the problem. The two-story house was served by a single air handler, located in the garage. Anyone familiar with construction knows that underneath the carpet, the subfloor usually consists of 4-ft x 8-ft sheets of plywood. The ductwork for the upstairs was located in the floor volume, between the first and second floors. One other clue for this problem was the Volvo with a diesel engine parked in the garage. The return duct connection to the air handler was very leaky, as were all of the supply ducts. When the homeowner warmed the car up each morning, the return duct sucked the exhaust from the car, and the soot then leaked into the floor volume from the supply leaks. The pressurized floor volume then pushed the air--and all that was in it--up through the seams in the plywood sheets making up the subfloor. The carpet served as the filter for this air.

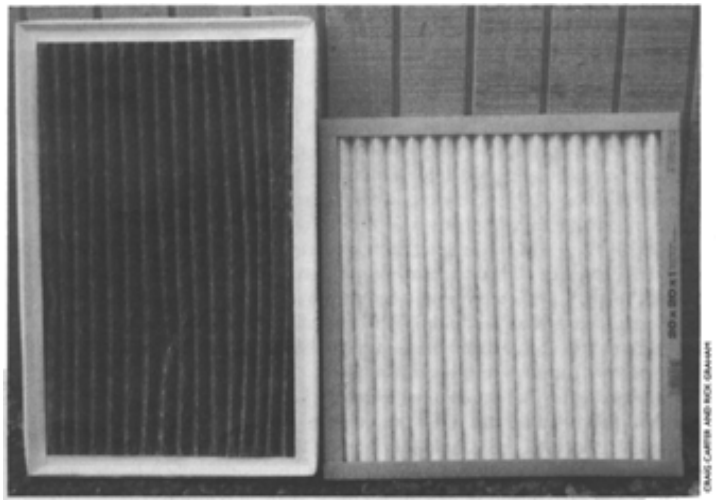
## Cleaning Up the Mess

Unfortunately, we don't have all the answers yet. We still have much to learn about the interactions among the various forces and pollutants involved in ghosting. What combinations of relative humidity, air velocity, and source pollutants are necessary to create a problem? How long must these factors be present before a problem is apparent? What factors might exist that we don't yet know about?

We do know enough, at least, to be able to begin taking positive action (see "The Ghosting Investigator's Checklist"). We know that houses work as systems. We know how to deal with driving forces by ensuring that the pressure and thermal boundaries of our houses are aligned. We know that houses should be tight and well sealed at the top, including wall-to-attic connections. We know that the air handler and ductwork function as an integrated system within the house system, and that they should be designed to complement one another and installed to meet recommended industry standards. We know that houses should be pressure balanced when the air handler and exhaust fan are in use and interior doors are closed. We know that insulation should be installed without compression and voids to avoid cold interior surfaces. On top of all of this, we know that houses should be performance tested to ensure that all recommendations and

specifications are met. Finally, we know that homeowners--as well as builders and trade allies--must be educated on house-as-a-system issues and the consequences of various actions.

## The Ghosting Investigator's Checklist



**A brand-new white pleated filter, right. A similar white pleated filter, left, after only two weeks of use in a house in which the air handler ran continuously and the owners burned a candle in a jar for two to three hours, three times a week.**

- The very first course of action when investigating a staining problem in a home is to identify what the stains look like and where they are occurring. Are the stains on any particular type of surface (for example, on plastics, on walls only, at carpet-to-wall junctions)? This helps to determine whether the problem is created by something going on in the house or by house construction details. Stains on wall and ceiling surfaces that are clearly geometric in pattern, may be caused by poor insulation. What color are the stains? Soot is generally black. Dirt and dust stains are gray, but if they are present long enough or in high enough concentrations, they can be near-black in color.
- A lab analysis of the stain is a nice--but expensive--luxury. If your clients can afford it--great; it beats guessing what the source of the stain is. If they can't, detective work is in order. Look for signs of occupant life-style and possible soot sources. Candles (look at the length of the wick--the longer the wick, the more soot it produces); pilot lights on combustion appliances (especially fireplaces). Make sure to examine the size and color of the pilot light. Excessively long or yellow pilots are possible sources of soot. Ask your client lots of questions about how they live. Maybe they burn a lot of candles, but only on holidays. You may not see any because they're packed away. Are there smokers in the house? How often do they use the fireplace and what type of wood do they burn (soft wood does not burn as cleanly as hard wood)? Examine the vacuum cleaner for possible contributions. If necessary, run it in a totally dark room, lit with a high intensity lamp. If the vacuum is spewing dust, it will be clearly visible.
- Don't neglect possible outside sources. Nearby high traffic areas, industrial settings, and construction sites are all possible sources for dirty pollutants.
- Conduct a thorough diagnostics test of the house. This includes a blower door test of house tightness and series leakage tests of attached garages, as well as a duct leakage test with a duct air tightness tester. Use an accurate digital manometer (with 0.1 Pascal readings) to pressure map the house. This includes measuring zonal pressures of floor volumes, attic and crawlspace/basement connections, chases, bypasses, wall cavities where stains are occurring, and stack pressures. Carefully measure what pressures are caused by duct leakage and interior-door closure. What are these pressures doing to any combustion zones, such as fireplaces or wood stoves?
- Look for insulation anomalies behind the walls where the stains appear. These are very common along kneewalls and trayed ceilings. Infrared scans are very useful here.
- Measure the duct velocity, using ACCA-recommended procedures. Examine the duct system as to material type and integrity.
- Carefully examine (and, where possible, performance-test) all combustion devices, including gas and wood log

fireplaces (be sure to check the chimney), wood stoves, furnaces, and water heaters. Look for signs of soot or cracked heat exchangers. Don't forget to examine the return air filter.

- Consider the extreme. One case involved possible contamination from a neighbor's improperly burning fireplace. Negative pressures in the client's home were pulling the smoke and pollutants in from next door.
- Consider "process of elimination" testing. If multiple pollutant sources are present, place several pieces of white acrylic plastic around the house. Eliminate all sources but one; then examine the plastic after several days. Continue until you have eliminated (or identified) all possibilities.
- Proper diagnostics--and more important, proper repairs-- require proper training. Improper repairs can actually make things worse, so if you're not sure what you're doing, call someone who has been trained.

Remember, soot stains (especially in new construction) are often the focus of legal charges. Be exacting in your diagnostics and keep accurate records that will stand up in court.

## This Little Light of Mine

Candles aren't the only source of soot production. But in the majority of cases investigated by several building scientists and energy specialists, candles were somehow related to the appearance of stains.

Rick Graham and Craig Carter of Air-Right Energy Design in Catharpin, Virginia, say that they have seen an alarming rise in soot-staining complaints over the last two years. "The complaints are generally the same, with black markings on carpets and baseboards, and black particulate dusting on kitchen appliances and television screens," Graham says. "We also find particulate on HVAC filters and supply registers and have even found the stuff in freezers." Graham says that in the majority of homes he's investigated, candles were the main source of sooting. "In comparing information from all of the houses tested and performing our own tests, we found scented candles, jar candles, and oil candles appear to emit a higher soot output than standard wax candles," Graham says.

Ron Bailey, an engineer and owner of Bailey Engineering Corporation (BEC) in Palm Beach Gardens, Florida, has had similar experience. Once an engineering design firm, BEC found an increasing demand for forensic engineering--figuring out why buildings are failing. Many of these cases involved soot problems, and Bailey soon began focusing on candle usage. He built a small test lab in his facility to study the various candle types and how well they burned. "My mother used to burn candles; why is it just now that problems are showing up?" Bailey says. "In the last five years, the candle industry has doubled. Where candle making once used to be an art form, it is now simply mass marketing. We suspect that the use of lower-grade waxes and materials is resulting in a higher oil content, which produces more soot when burned."

Bailey's tests include burning different candles in small chambers while passing air through the box and through a filter. To compare the amount of soot production with the length of time candles are burning in a house, Bailey uses the term "candle hours." One candle burning for one hour is one candle hour. Five candles burning for one hour is five candle hours.

"We have a builder client who's experienced a number of soot-related complaints," says Bailey. "He offered us use of one of his model homes to conduct some tests in. We burned four candles for a total of 15 hours (60 candle hours), which produced enough soot in the house that we were forced to stop for fear of creating too much damage in the house. We had significant soot production on the walls, drapes, dishwasher, refrigerator, and AC filter."

Bailey explains that there are two issues to consider when looking at how a candle might soot. "The length, thickness, and strength of the wick highly influence how a candle burns," Bailey says, "and also what is in the candle wax itself." Today, there is a growing trend in the use of aromatic candles. Fragrances added to the wax should be made specifically for that purpose. High temperatures can cause different chemicals to behave differently once burned. "Five percent paraffin wax is good," says Bailey. "But with many of the candles in stores today, we find a mixture of materials, including some fragrances that were not intended for this use." The mixture of the various fragrances and chemicals can result in a candle that is going to burn dirtier than expected.

Wise buyers should attempt to find out what type of candle they are purchasing and what quality of wax the candle is made of. Obviously, this is not an easy task. At the very least, then, buyers should keep an eye out for any soot stains. They can place a new candle near the TV (turned on). After a few candle hours, users can wipe the screen with a clean, white tissue. They can repeat this test periodically. If soot problems become apparent, users should stop using those candles immediately.

*Frank Vigil is a building science specialist at Advanced Energy Corporation in Raleigh, North Carolina.*