Wood Design FOCUS

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In This Issue:

Introducing the IICRC

In The Next Issue:

A Tribute to Dr. Robert White

Editorial

Several years ago, I was invited to attend a meeting of the IICRC, the Institute for the Inspection, Cleaning and Restoration Certification, a certification and Standards Developing Organization (SDO) for the inspection, cleaning and restoration industries. The IICRC currently serves more than 25 countries with offices in the United States, Canada, United Kingdom, Australia, New Zealand and Japan. This is a an industry group in the cleaning and restoration industry dedicated to developing standards and best practices related to any cleaning operation, which could include:

- Misuse or improper installation of products
- Disaster cleaning, including floods and fires
- Leaks and Water Damage /Pets
- Crime Scene / Medical Waste

This issue of *Wood Design Focus* is almost connected to the last issue about disasters. This issue answers the question "Now what?" when we have buildings that have sustained damage and must be made livable again. Just as architects and engineers talk about hazard mitigation to improve safety, or brainstorm scheduling problems to help work flow, there may be a time when your expertise is needed in a disaster or damage situation.

The four articles listed are reprints from the *Journal of Cleaning and Restoration*, which is produced by the IICRC. This is a peer -reviewed publication which brings together science and engineering to solve practical problems. Issues are available on the website for free and there is also a LinkedIn discussion group where you can engage with the authors and ask more detailed questions.

These articles include Martin King and Brad Kovar discussing how to identify combustion particles and trace them to their sources, Dan Stradford discussing the value and need to clear HVAC systems after disaster events, Jerry Blaylock presents a detailed description of how water vapor and enthalpy are involved in the drying of wood materials, and Jeff Bishop and Cindy Linden discuss the cleaning of fire retardants from structures.

I hope you find this issue helpful professionally.

Daniel Hindman, Editor

dhindman@vt.edu

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Distribution of Combustion Particles in Buildings

Martin L. King, ASA, CR, Brad Kovar, CIEC, CEICC, REA

Introduction

Despite the interests of building owners and occupants, it is generally acknowledged that the availability of insurance funds often determines the nature of repairs, or whether repairs occur at all. Since property insurance policies commonly deny coverage for pre-existing or ongoing conditions, a high priority may attach to distinguishing a “sudden and accidental” occurrence from ongoing effects. Authoritative studies have not addressed this question. Hygienists and laboratories are concerned with the nature and source of pollutants as they currently exist. There appears to be little need to explore the sequential aspect of particle deposition.

The experience-based world of damage repair has coined terms such as ghosting, filtration stains, nail pops, and smoke webs, to describe some patterns of settled combustion particles, neglecting the fact that identical mechanisms may characterize the behavior of domestic dust. This paper will attempt to analyze the pathways and deposit patterns of particles in buildings as they relate to domestic dust and combustion particles from fire events.

Temperature/Pressure

Building surfaces are heated and cooled by a variety of external and internal sources, some continuing, others fluctuating or seasonal. In general, building design seeks to minimize external influences in order to maintain a uniform and comfortable interior environment. However, temperature variation between surfaces is unavoidable. External temperatures may pressurize or depressurize attics and exterior walls. Fenestration and insulation add local temperature variations. Ventilation systems impose their own pathways.

Air molecules are energized by heat, which increases their kinetic pressure, and with fewer molecules occupying a given volume of air, warmer air rises and moves towards areas of lower energy. Greater energy also increases the ability of warmer air to carry particles. In this context cool and warm are relative terms, independent of specific temperatures.

Particle settling and accumulation involves general principles of air movement. For the purposes of this analysis, particles are defined as solid materials of a mass capable of being conveyed by air moving at relatively low velocity. The distance that airborne particles travel is inverse to their mass and proportional to their velocity. Mass in this case relates roughly to size, with the result that larger/heaver particles tend to settle out of an airstream earlier than smaller/lighter particles. As warmer air becomes diluted with cooler air, it becomes less able to carry particles, which progressively deposit as air movement slows. Minute particles (<100 nanometer) may stay airborne for extended periods of time, limited by air movement and the tendency to agglomerate. Differences in surface temperature may induce a selective accumulation of particles on cooler surfaces.

Particles

Dust - Particles are always present in air. Within buildings, airborne particles comprise an array of substances generated by materials and activities within the building as well as from exterior sources. The agglomeration of airborne particles into larger particles comprises the general category we call dust. Typical components of interior dust are granular particles, fiberglass fragments, textile fibers, hair, gypsum particles, epithelial (skin) tissue, plant spores, and insect fragments. Combustion particles also appear in domestic dust. Normally the individual components of dust are not separately visible, but an overwhelming presence of a single material such as sawdust or drywall debris may be visibly dominant after remodeling or refinishing. Absent such concentrations, the normal coloration of dust is grey. As dust accumulates it obscures underlying surfaces, and with sufficient time forms an opaque grey coating. Major dust components can be identified with standard reflected light microscopes at 100X-200X magnification.

Particles and their relative interaction with surfaces are dynamic in an occupied environment. There are several forces and principles which govern particle movement, suspension and re-suspension. Dust particles travel on normal convection currents and tend to deposit wherever an airstream meets obstructions, is deflected or slowed. An example of this is the downward flow of air adjacent a cold exterior wall or window. As the cooled falling air is deflected at floor level, some of the entrained particles settle out. The accumulation may become visible, since convection currents of this type tend to continue as long as the temperature differential exists. Gaps in the building envelope are often highlighted by an accumulation of dust particles filtered from air leaking through and around insulation. These dust filtration marks may be mistaken for smoke stains, especially when discovered after a fire event.

Dust particles exhibit polarity, the presence of discrete opposing electrical charges. Since opposite charges attract, dust particles tend to link together in chains, particularly where air is still. Often mistaken for spider webs (cobwebs), dust webs and strands may reach a foot or more in length. Polarity also explains the attraction of ionized dust to television and computer screens, whose polarity is inherent in their function.

Combustion Particles - Smoke is the visible airborne product of combustion, and consists of particles, liquids, aerosols and gasses, some of which condense as solids. As noted previously, combustion particles are a typical component of dust, generated by cooking, heating, smoking, fireplaces and external sources. Uncontrolled fires often generate concentrations of smoke particles sufficient to affect the appearance and utility of building surfaces and contents. Heavy smoke deposition is evident as a dark coating, often accompanied by a characteristic pungent odor. Depending on the fuel and fire temperature, combustion residues may be corrosive or exhibit other unwelcome chemical effects.

Settled combustion particles are called char particles and range in size from 1µ (.001 mm) to >500µ (.5 mm). The quantity, character and size of char particles vary with the fuel, term, and temperature of combustion. Char particles contain unburned fuel fragments, carbon, tars, resins and other substances. Very fine particles < 1µ (e.g. carbon), may be present in sufficient quantity to darken a test wipe.

The heat of combustion produces ionized particles, which, like dust, readily link together in chains and webs. For the same reason, settled combustion particles tend to bond preferentially with plastics, synthetic fibers and polymer-based coatings.

Rapid vs. Slow Combustion - Blazing fires produce particles distinctly different from those emitted by smoldering fires. Blazing fires are oxygen-rich and burn vigorously. Cellulosic fuels are more completely consumed (oxidized) and their particles tend to be small. Propelled by high heat, smoke rises swiftly and follows a visible path.

In contrast to rapid combustion, smoldering fires tend to be oxygen-deficient and burn at lower temperatures. As a result they consume fuel less completely, often smoldering for long periods before breaking out as full combustion. Particles from smoldering fires tend to be more ionized, viscous and malodorous than the products of blazing fires. Because they are not driven by high heat, particles from smoldering fires tend to travel on normal air currents. Moving slowly, they permeate a wider area and find their way into crevices and cavities bypassed by more turbulent smoke. It should be noted that blazing fires can pass through a smoldering phase, so the characteristic residues of both may be present. After active ignition ceases, air currents gradually return to their normal patterns, distributing entrained particles as they go.

Odors - Smoke odors are usually thought objectionable, sometimes extremely so. However, the perception of odor is an individual experience: the character and intensity of an odor cannot be objectively characterized. Char particles are often the source of smoke odors, and the odor potency appears to increase with particle quantity. Smoke odor is not always related to visible particles: the slow combustion of proteinaceous matter may emit no visible residue but affected surfaces often emit an obnoxious and persistent odor. The absence of discernible odor in dust provides a clear distinction from smoke particles and may explain the greater toleration that dust enjoys, compared to the urgency of locating and removing malodorous smoke particles.

Furnace Soot - A distinction exists between the products of active fires and furnace soot. Furnace soot is the product of a controlled combustion system (the furnace) that fails to adequately burn its fuel. Soot accumulation in the fire box increasingly disrupts the flow of combustion air. A sudden ignition may result in a mini-explosion popularly termed a *puff-back*. Forced-air systems distribute the dislodged soot along with the heated air. If air ducts are not present (such as in steam or hot water systems) the soot is broadcast from the furnace and the accumulation can be tracked to that area. Lacking propulsion from heat, furnace soot is conveyed by normal air currents, its path marked by visible accumulations of dark particles. Like dust, furnace soot does not emit the smoky odors associated with the products of accidental combustion.

Candle Smoke - Candles are used in residences for visual effect and for their scent. Commonly employed at formal dinners, they are also used for ceremonial purposes and are often displayed unlit for their aroma. Candles may be housed in glass cylinders or vases, with scented varieties reaching two or more inches in diameter. Aroma-producing devices may plug into wall receptacles and vaporize perfumed oils. So-called “smokeless” candles have been found to create visible combustion particles when ignited. The quantity of particles produced by candles varies from areas of severe darkening to faint deposits on lift samples. Candle emissions tend to accumulate near their source, minute particles often clustering at ceiling/wall angles.

External sources- Externally produced combustion particles can infiltrate buildings in significant quantities. Wildfire smoke is a common example. Wildfire particles tend to accumulate on exterior surfaces and at building penetrations, and may include wind-borne granular materials from the fire area. Within the structure, infiltrated particles respond to normal air flow.

Particle Distribution

Ventilation systems - Air ducts are conveyers of particles as well as targets for particle settlement. Ventilation systems create their own distribution patterns of heated or cooled air. Even when a system is dormant, ducts may transport air by convection. The temperature difference between ducts and ambient air may cause particles to accumulate on both the interior and exterior of ductwork. After a fire, settled combustion particles may become re-entrained by air movement and continue to distribute via the ventilation system. Particulates collected by filters and blowers can provide a snapshot of particle identity and concentration.

Open and Enclosed Spaces - Particle deposition in building interiors is moderated by the differing characteristics of open and enclosed spaces. Open spaces consist of rooms and areas that are accessible, visible, and directly served by the building’s ventilation system. Enclosed spaces are the cavities within partitions, walls, ceilings, chases and soffits. These voids are sometimes referred to as *interstitial spaces*.

Not subject to the temperature variations and air currents that characterize habitable areas, air within enclosed spaces is relatively still and its ability to retain particles substantially diminished. Air that is able to infiltrate loses entrained particles, resulting in long-term dust accumulations that are commonly found in enclosed spaces. Combustion products sometimes find avenues into enclosed spaces and may generate lingering smoke odors.

Interstitial spaces - Building architects sometimes design intermediate spaces between floors to house HVAC units, communications equipment, electric cables and other utilities designed to serve a specific floor. Called interstitial spaces, these cavities commonly have concrete floors with lowered ceilings and may extend over a full floor or a portion of it. Large buildings may have alternating interstitial floors, constructed to free the functional space from penetrations and chases that might inhibit modification or redesign.

An interstitial area acts as an enclosed space. Even though floor and ceiling penetrations are intended to be sealed, dust and combustion particles find their way in. During a fire, smoke particles may deposit on the tangle of electronic cables and hardware, raising problems of corrosion and odor.

Deposit Patterns

The physics of combustion, air currents and particle transport often produce characteristic deposit patterns. While many patterns are shared by dust and combustion particles, after a fire or furnace malfunction the high contrast of combustion particles tends to attract immediate attention. Some typical patterns of particle settlement are listed below:

Figure 1. Smoke Webs

Figure 2. Ghosting Present At An Electrical Outlet

Smoke webs and smoke chains (Figure 1) - These are sometimes mistaken for existing cobwebs that have attracted smoke particles. Actually the strands consist entirely of linked combustion particles. A source of the confusion may be the tendency of both smoke-webs and dust-webs to form in areas of still air, such as wall/ ceiling corners. Smoke-webs do not require pre-existing dust webs for support.

Ghosting (Figures 2 and 3) - This is a term applied to the shadowy outlining of electrical outlets and wall-hung graphics that often appears after fires. The air behind a wall-mounted artwork is still. As warmer smoke-laden air approaches the perimeter and slows, graduated shading reflects the release of particles. A similar mechanism may appear as vertical stripes on exterior walls when studs provide a thermal bridge between the exterior sheathing and interior drywall. Junction boxes displace insulation when installed within exterior walls, resulting in a colder surface around wall outlets and a typical deposit pattern of combustion particles.

Nail Pop (Figure 4) - This describes an optical illusion created by ionized particles attracted to metal nails hidden beneath the joint compound of drywall. The graduated particle accumulation suggests a protruding nail head, which disappears with cleaning. Painted drywall ceilings are especially prone to this effect.

Figure 3. Ghosting Present At A Smoke Detector

Figure 4. Ghosting Present And Nail Pop

Figure 5. Smoke-Streaked Insulation

Filtration marks (Figures 5 and 6) - This describes dark streaks or splotches on the surface of insulation and dark lines on carpets. In both cases the discoloration consists of particles filtered from air in response to a pressure differential. The same mechanism may produce a dark horizontal shadow above a baseboard heater. These discolorations are not necessarily caused by a smoke incursion, since accumulated dust can develop considerable opacity. Negative pressure at a lower floor sometimes creates streaks on carpeting that mirrors the outline of subfloor joints. These accumulations reflect ongoing air flow, but often leap into prominence after a fire or furnace puff-back.

Threshold streaks (Figure 6) - These are filtration marks that appear in carpeting at an entry door. A pressure imbalance sometimes arises when remote supply vents do not adequately feed a central air return, creating a zone of negative pressure. The constricted air passage permits carpeting to filter particles from the air stream, creating a visible streak. The same mechanism may lead to filtration lines in carpeting along baseboards.

Selective deposition - This describes the variable attraction of dust and combustion particles to specific surfaces. The selectivity may be a response to transient differences in temperature (see ghosting, above) or inherent differences in polarity. The latter explains smoke particles adhering to vinyl and acrylic paint more readily than to oil paint. A chair upholstered in nylon will attract more particles than an identical chair covered in cotton fabric, and will retain the particles more tenaciously. Dust exhibits the same response, as attested by its accumulation on computer monitors and TV screens.

Geometry of Interior Spaces

An accurate assessment of smoke impact requires sufficient knowledge of construction to anticipate the affect of airborne combustion particles on building components. This is especially important when combustion particles are corrosive or emit strong odors. For example, a failure to recognize the potential of a suspended ceiling to hide corrosive particles may have a substantial impact on vulnerable metals. Weeks of shutdown have been spent searching for the source of a strong smoke odor whose location was fairly predictable, based on the physics of building layout and air movement.

Ceilings - Ceilings may form a continuous unbroken surface or employ modular elements such as acoustic panels and supporting tracks. In residences and many commercial buildings, the ceiling is directly affixed to solid joists or rafters, creating discrete channels blocked at the ends. Horizontal chases and lighting fixtures may interrupt the exposed ceiling as well as the enclosed air space.

Commercial construction often employs web joists over suspended ceilings to form an open cavity that houses air ducts, light fixtures, wiring and other utilities. The ceiling cavity itself may serve as a return air plenum. Thus, ceiling cavities may be open, filled or partially filled with insulation and utilities. Some ceilings permit air movement while others retard it.

Figure 6. Carpet Filtration Lines, Threshold Streak

The presence of ceilings as barriers to rising air currents renders them vulnerable to incursions of smoke as well as dust. The still air over a suspended ceiling often attracts heat–driven smoke particles and is often a primary focus of post-fire inspections. When a ceiling is breached by fire, the tracking of smoke and settled particles becomes more pressing because of potential corrosion and remote odor sites.

Exterior Walls - In traditional frame construction, exterior walls consist of uniformly spaced studs separated by fire stops and horizontal framing. Studs may be solid wood, or preshaped metal. The latter will be affixed to metal channels. Metal studs allow air movement by virtue of precut openings for wiring. The exterior wall surface is usually enclosed by some form of sheathing. The vertical pockets between studs are filled with insulation. The assembly is covered with an interior finish, usually drywall, paneling, or in older homes, plaster. The sole and top plates have penetrations for wiring and plumbing lines that may form channels for airflow.

Solid masonry or concrete walls often employ metal studs or horizontal furring for drywall. Both provide air space between the masonry and the interior finish if not filled with insulation.

Masonry veneer construction introduces an inaccessible drainage plane (air space) between the sheathing and masonry. Sheathing for masonry veneer walls is usually attached to traditional stud framing. If fire breaches the sheathing, the combustion particles between the masonry and sheathing cannot be accessed directly. Insulation above and below windows (and often other areas) is sometimes casually installed and subject to air seepage and resultant filtration stains. These dust accumulations are sometimes interpreted as evidence of infiltrated smoke.

Partitions - Partitions are essentially closed boxes. Occasional penetrations may be cut for electrical outlets or switches, and in top or bottom plates for wiring. Studs may be drilled to permit a horizontal run of electric cable. Metal studs have spaced perforations that permit airflow between stud pockets. However, the absence of connections to other assemblies tends to restrict air circulation within partitions.

Chases and soffits - Chases are finished enclosures designed to house plumbing, electrical or other utilities. Horizontal chases often enclose air ducts. Vertical chases most often enclose plumbing and electrical lines. Kitchens and bathrooms are often stacked vertically, connected by chases or wider chase walls. Ceiling penetrations may allow convection currents to carry particles to higher floors. The interior dynamics of a chase may depend on the system it houses. For example, the air surrounding HVAC ducts may be warmer or cooler than the ambient air. During a smoke incident, positive or negative pressure within a chase can determine if it attracts particle accumulation. After a kitchen fire, substantial combustion products and odors are often encountered in an upper bath.

Soffits cover structural voids and irregularities for cosmetic reasons. Soffits over kitchen cabinets are a common example, and may be open to wall and ceiling cavities, a factor in their ability to convey combustion particles.

Stairs - Soffits covering the underside of stairs are both repositories and conveyers of smoke, often connecting the ceilings of adjacent levels. Stair soffits are vulnerable to heat-driven smoke particles and odor because of the stack effect and the fact that stair carriages may be inaccessible to treatment when adjacent a wall. Tread mortises may be loosely-fitted, providing voids for particle deposit. For these reasons, stair assemblies tend to retain combustion particles and odors.

Attics - In residential construction attics are usually vented at gable ends, eaves, or both. The vents supply a continuing flow of exterior air which deposits an array of particles on exposed framing and insulation. Attic particles may contain combustion particles from chimney smoke and automotive exhausts, in addition to other external fire products. As a result, attics are not reliable indicators of interior combustion damage unless smoke odor is present or interior paths clearly exist. When attics are directly involved in a fire, the unfinished framing is able to absorb combustion products, amplified by the inaccessible corners and minimal headroom that usually exists at the eaves. Opening ceiling access from below is one way to reach these areas.

Bathrooms - Cold ceramic tile and porcelain finishes make bathrooms conspicuous targets for combustion products. The condensation of combustion vapors may cause permanent stains. Chase walls for plumbing may facilitate smoke distribution between floors. The space surrounding bathtubs is a frequent repository of particles and odor, with Jacuzzi equipment especially vulnerable. Use of hot showers or baths may activate smoke odors long after repairs have been completed.

Kitchens - Since fires often originate in stoves and ovens, the spaces behind and between cabinets become candidates for accumulating and transmitting combustion products. This normally unobstructed space may also serve as a route to a soffit or ceiling cavity. Access to this area via the soffit or ceiling may be less disruptive than cabinet removal. Treating smoke odors may be impeded by the absence of visible fire residues after so-called protein fires.

Fireplaces and Chimneys - While sharing the general characteristics of chases and soffits, fireplace surrounds and chimney chases may be independent sources of combustion particles and smoke odors. Clearance requirements create vertical cavities around chimneys that may permit downdrafts and carry odors into the living space. Faulty or aging flue sections often have cracks or voids that permit combustion products to escape and coat interior walls of the chase. Such on-going smoke odors may be mistakenly blamed on fire damage elsewhere in the building.

Ambiguous Deposits - The scrutiny that follows a smoke incursion may reveal dust accumulations that are mistakenly perceived to be new. Despite evidence to the contrary, the error sometimes hardens into certainty. Areas susceptible to misinterpretation include:

- *Recessed light fixtures*. These are frequently surrounded by insulation which filters particles from the convection currents generated by the fixture's heat. A dark ring on insulation surrounding the fixture is an ongoing condition unrelated to a single incursion of smoke.

- *Hanging fixtures and chandeliers*. The convection currents created by a fixture's heat tend to deposit dust particles at any deflection or interruption to the vertical flow of air. Thus, the canopy, junction box and adjacent ceiling tend to accumulate visible dust. The plastic or cardboard "candles" that enclose the bulb sockets on chandeliers often display a noticeable buildup of dust particles. Electrostatic attraction may play a role in this accumulation. When located over a table where candles are burned, the prisms and arms of a chandelier may collect combustion particles as well as dust.

- *Ceiling fans*. The blades of circulating fans create a zone of negative pressure above the blades. As a result, the upper surfaces of revolving fan blades tend to accumulate dust, and cannot serve as accurate indicators of combustion products. Insulation around ceiling exhaust fans often displays smoke-like streaks from induced air currents.

- *Electronics*. Since opposing polarities attract, audio speakers, computer monitors, television screens, and many other electronic devices tend to attract particles by virtue of their opposing static charges. In computers, the power supply tends to attract more particles than other components and may provide a quick estimate of particle concentration.

Dust or smoke?

For insurance, the distinction may be critical: a "sudden and accidental" loss may be covered, while an ongoing accumulation of particles is not. Since dust and smoke particles respond to the same forces, the distinction between them is not always clear. Long-term dust accumulations may approach the opacity of combustion particles.

Tracking settled particles to a source is based on the principle that particle accumulation is greatest near the point of origin. A trail of progressive intensity (or its absence) may indicate a source. Examples of this are the typical deposit patterns of tobacco smoke and fire place emissions. However, a layer of combustion particles will be significant no matter how dense the underlying dust may be, and the sudden appearance of a smoke odor tends to resolve identity questions. Microscopic analysis of lift samples offers a swift and inexpensive way to distinguish settled combustion particles from normal dust components.

Damage

Particles may be chemically described, weighed, measured and counted, but the existence of damage is a subjective judgment. The authors are aware of no generally accepted standard that relates the presence of combustion particles to damage. There has been no attempt in this paper to address the issue.

Conclusion

Since dust particles and combustion products are often similar in their distribution patterns, identification may hinge on their relative intensities. A problem sometimes arises when combustion particles are not readily visible or have penetrated enclosed areas. Unlike dust, combustion particles may corrode metals and generate odors. For these reasons, analysis of likely collection sites is more than an academic exercise. Combining knowledge of buildings with the principles of particle distribution can provide a logical basis for investigating hidden odors and distinguishing settled combustion residues from dust.

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Martin L. King, CR, ASA, is the founder and CEO of Martin Churchill Associates, Inc., damage investigators and appraisers. *martinch@erols.com*

Brad Kovar is the founder, president and CEO of Safeguard EnviroGroup, Inc. *bradkovar@aol.com*

Determining the Need for HVAC Cleaning in Restoration Work

Dan Stradford

Introduction

In October 2007, a fire began in Southern California's Witch Creek Canyon. Fueled by dry conditions and winds up to 100 mph, it rapidly grew into an ominous gray cloud of smoke and flying embers that spread for miles across the horizon. It would become the second largest wildfire in the state's history. As the Witch Creek Fire burned out of control in a 50-mile march toward the Pacific coast, a second conflagration, the Harris Fire, laid down another path of destruction in the same region from the Mexican border toward San Diego.

In a mass evacuation, the residents of at least 346,000 homes were ordered to leave their properties. Between the two disasters, 1,900 homes and outbuildings were destroyed.

What the public did not hear much about were the buildings that remained. Restoration contractors and insurance adjustors from across the U.S. quickly descended on a swath of housing tracts that sprawled across the desert landscape, where tens of thousands of homes and other buildings had survived the worst but were scarred by smoke, ash and occasional flames.

Painting, carpet remediation, deodorizing — most of the needs were obvious. But among many of the adjusters and project managers who walked the properties in the aftermath, the question was asked, "Do the HVAC systems need cleaning?"

After all, HVAC systems are the lungs of the building, and like humans, they suffer the effects of smoke inhalation, particularly if they were operation during a fire.

Understanding HVAC

An HVAC (Heating, Ventilation and Air Conditioning) system typically consists of:

1. The *air handler* or HVAC unit that drives warmed or chilled air into the building. The air handler components are:
    a. a filter rack and filter(s),
    b. a fan or blower,
    c. a cooling coil for chilling the air, and
    d. a heating element (heating coil, heat exchanger) for warming the air.
2. The *supply ducts* that bring air into the building.
3. The *return ducts* that draw air from inside the building back to the HVAC unit.
4. The *fresh air intake*, an opening or short duct that brings air from the outside into the HVAC unit. Typically air handlers take in a combination of fresh air and interior air pulled from the return ducts, then warm or cool this air and send it into the supply ductwork. (This is often how HVAC systems and structures are contaminated with outside smoke and ash, even when the building is sealed.)

The Basics of HVAC Cleaning

Cleaning HVAC systems typically follows a certain sequence:

1. Registers are removed for washing.
2. Ductwork is cleaned from the register openings or through holes cut into the ductwork, if needed. (Any cut holes are later sealed.)

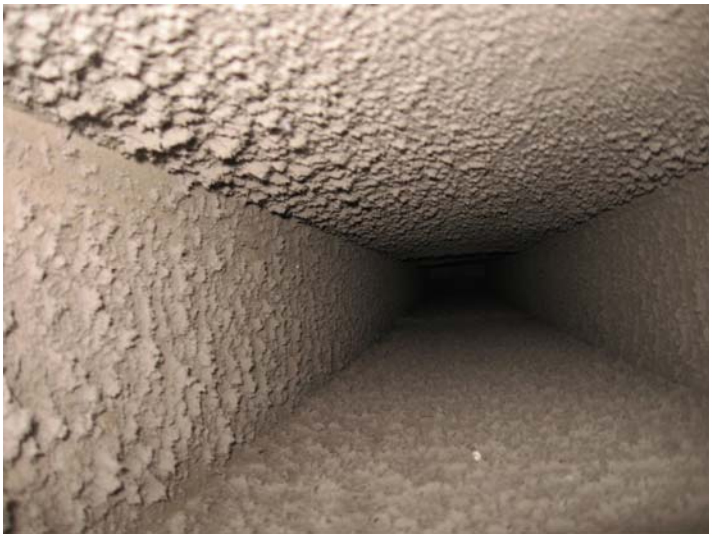

Figure 1. HVAC Duct Before Cleaning

Figure 2. HVAC Duct After Cleaning

3. Flex duct, if present, is disconnected as needed to gain access.
4. Ductwork interior can be cleaned and vacuumed via brushes on cables, air agitation or using direct hand vacuuming.
5. Air handler components are typically cleaned and vacuumed by hand.
6. In some circumstances, portions of HVAC duct interiors may need to be washed by hand.

When HVAC Cleaning is Recommended

The primary international standard for HVAC cleaning was developed by the National Air Duct Cleaners Association (NADCA) in the early 1990s and is known, in its most recent edition, as the Assessment, Cleaning, and Restoration of HVAC Systems (ACR 2013) or simply “the NADCA Standard.” (NADCA 2013) The NADCA Standard was developed in close compliance with other industry standards, including those of the Institute for Inspection, Cleaning and Resortation Certification (IICRC), ASHRAE, the Sheet Metal and and Air Conditioning Contractor’s National Association (SMACNA), and the North American Insulation Manufacturers Association (NAIMA).

Page six of the ACR 2013 lists the conditions for which HVAC cleaning is recommended. For restoration contractors, these conditions include:

- The system is contaminated with an accumulation of particulate.
- The system performance is compromised due to contamination build-up.
- The system has been determined to be a source of unacceptable odors.
- The system is discharging visible dirt or debris into the conditioned space.
- The system has been contaminated as a result of fire, smoke, and/or water damage.
- The system has been infested with birds, rodents, insects, or their byproducts.
- The system has been determined to be at risk for fire hazard.
- Mold contamination conditions have reached either Condition 2 or Condition 3 (as defined in IICRC S520 (IICRC 2006)).
- Deterioration of fiberglass duct liner, duct board, or other porous components. (NADCA 2013)

Let’s examine these situations individually.

Particulate Contamination- Although particulate contamination can occur from fire or water damage, as will be discussed, disaster cleanup of HVAC systems also can be required when any mishap or unhygienic condition reaches the point of worst-case scenario.

A common source of trouble is when the HVAC fresh-air intake or return duct openings are located in areas exposed to high levels of particulate or airborne contaminants. For example, a maker of women’s makeup products failed to control the emission of talcum powder during the manufacturing process, which resulted in massive particulate buildup in the HVAC

Figure 3. Coil Before Cleaning

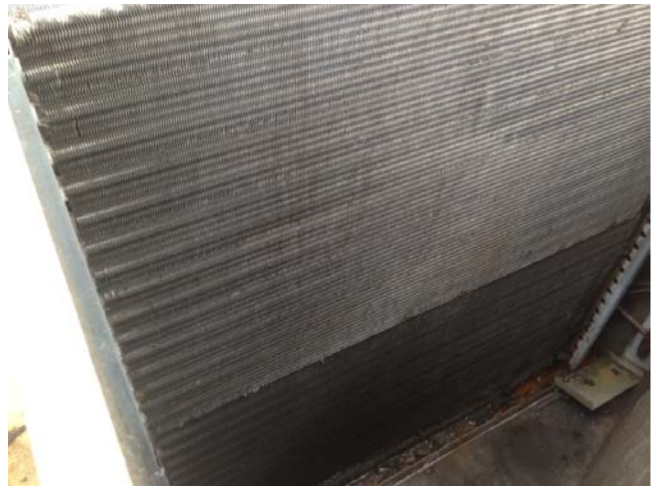

Figure 4. Coil After Cleaning

system and other areas, culminating in an emergency that required professional restoration.

A pharmaceutical company demonstrated similar neglect of engineering controls when it failed to prevent the suction of its products into the HVAC system. Over a hundred pounds of drug capsules, tablets, and dust were removed from the ductwork. Although this particular situation was caught before any legal ramifications were triggered, had the authorities become involved, the building would have almost certainly been shut down and full disaster restoration required.

Compromised HVAC Performance- The primary ways in which HVAC performance is compromised are:

1. Reduced or no ability to cool or heat.
2. Restricted or no air flow.
3. Unbalanced air flow (flow not reaching all distribution points as planned).

In the duct cleaning world, the main culprit in reducing cooling or heating function is particulate buildup on the cooling and/or heating coils. In fires, this usually is soot and ash. In floods, it usually is mud or other floating debris, even mold buildup if the HVAC system has been inoperative for a while after water damage has occurred.

A cooling coil looks very similar to a car's radiator with many rows of metal fins aligned close together to allow for maximum distribution of cold air from the coil. This configuration, however, also invites rapid clogging and reduction of efficiency when particles or debris accumulate on coils and block the airstream.

Coils are so sensitive to particulate buildup that one 2006 study of large air handlers in a New York City high-rise found that coils cleaned after one year showed improved air flow of 14 percent and energy savings of up to $40,000 per year (Montgomery and Baker 2006).

In the chaos of a disaster, clothing, cardboard, building insulation, construction debris — all manner of materials — can be sucked into or somehow land in an HVAC system and block the cooling or heating coils, greatly reducing their effectiveness. Similarly, such blockage can wind up in the ductwork, dramatically restricting or unbalancing airflow. In these situations, HVAC cleaning is necessary to restore efficient system function.

Also, damage can be caused by first responders. Firemen and other emergency personnel sometimes step on, squash, disconnect or puncture ductwork, exposing the interior to contaminants. After the system is repaired, cleaning may be in order.

Unacceptable Odor in HVAC Systems- Odor in HVAC systems can occur on a molecular level, such as smoke residue clinging to the metal of the duct interior, or it can come from actual debris or objects (such as dead animals) in the system.

Odor removal methods, such as ozone or chemical deodorizers, can be effective in altering thin layers of residue chemically so they no longer produce a detectable smell. However, the IICRC recommends removal of the odor source whenever practical (IICRC 2012).

Sizable particulate or masses such as ash, cinders or sewage usually will continue to emit odors unless they are physically taken out of the HVAC system. Additionally, most duct systems are already soiled with a layer of dust and debris before the disaster occurs. Smoke or water entering ductwork saturates the debris that is already there, making it difficult, if not impossible,

Figure 5. Soot Contaminated Filter

to eliminate odors without removing this pre-existing — and now odor-permeated — blanket of particulate.

In the case of the Witch Creek Fire mentioned at the beginning of this paper, thousands of homes were left with smoke odor. Hundreds of homeowners had to have their HVAC systems cleaned as an initial step in removing smoke odors.

Dirt or Debris Discharging from the Ducts- The state of California and other governing bodies recommend that HVAC systems be turned off in a fire setting (Calfire 2012) However, as a practical matter, that rarely happens unless the system is equipped with smoke or fire monitors. As a result, ash, cinders and other wind-borne particles frequently get sucked into the return duct (s). They typically load up and partially penetrate the HVAC filters and they can migrate into the supply ductwork as well.

Consequently, it is not uncommon to have debris discharging from registers when the unit is turned back on after a fire. This will often continue unless the system is cleaned.

Sometimes other disasters can bring this about. Earthquakes can shake loose debris in the ductwork that had been adhering to the metal. Tornadoes or high winds can drive dirt, leaves, and other materials into a system. Extreme neglect, such as leaving HVAC filters out for an extended period, can foul a duct system to the point that accumulated material starts “peeling off” and blowing out.

HVAC Damaged by Water and Fire- A typical HVAC unit puts out about 400 cubic feet per minute (cfm) of air per ton of cooling capacity (Hastbacka et al. 2012). This means a typical five-ton unit supplies 2,000 cfm. Given that an average five-ton unit will only have 100-200 cubic feet of ductwork, we can see that once smoke and ash reaches the return registers or fresh air intake, it can be transported very rapidly through the ductwork, often in a matter of seconds.

Thus, the HVAC system can be one of the first casualties in a fire and it can often be the primary vehicle for smoke and fire being transported to the rest of the structure.

Similarly in flooding, if registers are on the floor — more common in a residential setting — the ducts may be one of the first victims of the crisis. While contaminated water, such as river flooding, must be cleaned out, even tap water getting into the ducts mixes with the existing debris to create a soup that promotes microbial growth and rust.

If the ductwork or air handler is not physically damaged by fire or water, cleaning is often an appropriate next step. Even if part of the system, such as the HVAC unit, is ruined, one may be able to replace that part and recover the remainder of the system through cleaning.

Emil Dilanian, senior project manager of Tri-Tech Restoration’s Burbank, CA facility, states, “In most cases if the fire is internal, the HVAC system or certainly those components exposed to severe smoke and heat, will usually need replacement. But if the smoke is from an exterior source or not too close to the fire source, a cleaning can be sufficient. If there is some question, we will call in an HVAC cleaning contractor to assess the situation.”

But what if there is still uncertainty about whether the HVAC system has been impacted enough by fire to require cleaning? In a large building such as a hospital, the HVAC system could be huge, with considerable expense involved to clean it. The adjuster may want to decline cleaning to cut costs, but the restoration contractor or client may believe that cleaning is warranted.

To resolve this debate, the “Soot Standard” was developed. The ANSI IESO/RIA 6001-2011 *Evaluation of HVAC Interior Surfaces to Determine the Prescence of Fire-Related Particulate as a Results of a Fire in the Structure* was created by the joint effort of the Indoor Environmental Standards Organization (IESO) and the Restoration Industry Association (RIA) (ANSI 2011). The standard outlines specific protocols, utilizing lab testing to determine if there are sufficient levels of char and soot in the HVAC system to warrant cleaning.

Infestation from Birds, Rodents, Insects or Their Byproducts- Some disaster specialists include pest cleanup in their résumé. These commonly include horrific conditions of neglect or acts of nature.

Infestations frequently are caused by pigeons roosting in or near HVAC components and possibly within ductwork. This can occur, for example, when city or school budgets are reduced and HVAC systems are not inspected for extended periods, or when building owners simply try to save money on HVAC maintenance. The result can be serious exposure to disease or allergens for the building occupants.

Rats are a common problem in residential systems. They can chew into flex duct, nest in parts of air handlers, and tear off and horde duct insulation — internal or external — for their dens.

Since commercial air handlers are usually on roofs, birds in general are common problems, sometimes even building nests at the top of the duct that exhausts combustion gasses from the gas heater in the air handler, causing carbon monoxide to backup into the building.

Different regions of the U.S. and the world have pests unique to their areas that can ruin or contaminate HVAC systems. If a company's operations expand into a new state or territory, restoration technicians can find themselves contending with creatures they've never dealt with before.

Some, but not all, HVAC cleaning firms will tackle pest cleanup, depending on how pervasive and potentially toxic the situation is.

When the System is a Fire Hazard- Numerous scenarios can make an HVAC system a fire hazard. Combustible materials such as flammable chemicals, leaves, pine needles, paper products and kitchen grease can be and have been found in ductwork. If these flammable materials get near the heating element in the unit, a hazard exists.

After a fire, particular attention should be paid to the wiring of the air handler and thermostat. As with any electric wiring, if the insulation is melted, exposing bare wires, sparks can occur leading to ignition of any flammables in the vicinity. And just because HVAC systems, per code, are made of low-flammability materials, don't assume there is nothing to catch fire. Pet hair, dander, lint and a wide variety of flammable materials can build up in a duct system over time and can burn if given an ignition source.

A hidden fire hazard in HVAC units after a fire can be the blower. These fans commonly rotate on a shaft that spins on a bearing on each end. These bearings are sometimes packed in grease that can melt or burn out under the high heat of a building fire. Even if the air handler survives the fire, if the blower has been exposed to extreme heat, be careful that the bearings are not now without lubricant and rubbing metal-on-metal. The resulting friction or sparks can start another fire.

Mold Contamination in the HVAC System- The Environmental Protection Agency (EPA) is very clear about using an HVAC system that may have a mold issue: "Do not run the HVAC system if you know or suspect that it is contaminated with mold" (EPA 2012).

The remediation of mold-impacted HVAC systems is covered in the IICRC S520 *Standard and Reference Guide on Professional Mold Remediation* (IICRC 2013). If there is reason to suspect the existence of mold within, it should be inspected and, if necessary, cleaned in accordance with the NADCA ACR 2013 Standard or its equivalent. The NADCA Standard recommends that the system be cleaned if the presence of mold has reached Condition 2 or Condition 3 as defined by the S520:

Condition 2 (settled spores): An indoor environment, which is primarily contaminated with settled spores that were dispersed directly or indirectly from a Condition 3 area, and which may have traces of actual growth.

Condition 3 (actual growth): An indoor environment contaminated with the presence of actual mold growth and associated spores. Actual growth includes growth that is active or dormant, visible or hidden.

Water, of course, is required for mold growth, and water is inherently associated with HVAC systems. Besides conveying sometimes humid air through the ductwork, the air handler has cooling coils that may drip water into a condensation collection pan below the coils. It is not uncommon for these pans to become clogged, leaving standing pools or saturated areas that support microbial growth. In fact, the HVAC system could be the source or distribution vehicle for mold spores in a building.

Larry Enos of All Clear Environmental in North Hollywood, CA, has a rule of thumb if there is some question about whether the HVAC should be cleaned on a mold job. "Normally, we follow the recommendations of the indoor environmental specialist who assesses the project. But if I find excess mold spores in the air samples of a room distant from the water source, or in two or more rooms, my experience has taught me that it's wise to clean the HVAC. There's a strong likelihood the mold is somehow migrating from the duct system."

Deterioration of fiberglass liner or other porous components- One of the most common calls received by duct cleaning contractors is that of particles blowing out of the system. Frequently this is due to damaged fiberglass liner inside ductwork or the air handler that is gradually flaking off in the airstream. The only cure is cleaning followed by repair and recoating or sealing of the liner. If the liner is beyond repair, removal and replacement may be necessary. In some cases, the labor and material cost of liner replacement is too extensive or impractical and the ductwork has to be replaced.

In dealing with fiberglass liner and similar HVAC components, the NADCA Standard turns to the North American Insulation Manufacturers Association (NAIMA) and its guide *Cleaning Fibrous Glass Insulated Air Duct Systems* (AH 122) (NADCA 1.

Accordingly, Section 4.17 of the NADCA Standard states, "It is recommended that porous materials with mold growth (Condition 3) be properly removed and replaced (NADCA 2013). This task shall be followed by surface cleaning using mechanical cleaning methods." In short, there is no way to clean or save the liner if it has Condition 3 mold growth, but replacing the liner may be a cost-effective alternative to replacing the ducts or air handler, depending on the situation.

In cases where liner has been roughed up but not ruined in a disaster (with sand, for example), cleaning and surface repair with a coating or insulating material can often restore the system.

Summary

Today, thousands of homes that survived the Witch Creek Fire comfortably house residents who see or smell no remnants of the inferno that swept through their communities less than a decade ago and made their living quarters temporarily uninhabitable. The stained surfaces have been repainted, smoke damage restored, and for many, the HVAC systems have been cleaned.

To restore a property to pre-disaster condition, adjusters and project managers need to be familiar with all of a structure's components that can be impacted by fire, flood and other cataclysmic events. This includes understanding HVAC systems and the reasons for cleaning them as outlined in the NADCA Standard and the IICRC standards.

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Dan Stradford is the CEO of Action Duct Cleaning in Los Angeles, CA. dstradford@aol.com

An Examination of the Role of Vapor Pressure and Enthalpy in Drying Water-Damaged Structures Containing Wood-Based Products

Jerry Blaylock

Abstract

This study investigates water vapor pressure as measured in inches of mercury (in Hg) and enthalpy (*h*) within ambient air and water-damaged wood-based building products. Water vapor pressure and enthalpy differentials between ambient air and wood building products below fiber saturation point were analyzed using the Energy Transfer Rate (ETR) model. SPF (spruce, pine, fir) framing lumber and red oak hardwood flooring were tested and assessed. It was determined that the largest moisture content reduction resulted from the largest vapor pressure and enthalpy differential. Importantly, it was determined that the reduction of the humidity ratio — expressed in grains per pound — within the environment was not the largest contributing factor in moisture content reduction.

Introduction

In drying water-damaged structures, understanding and applying the equilibrium moisture content (EMC) chart (Table 1) can be instrumental in evaluating drying efficiency. In this paper the science of EMC from the wood-drying industry is integrated into the services

Table 1. Equilibrium Moisture Content (EMC) Values

Relative Humidity	Temperature of Materials														
	70°F	75°F	80°F	85°F	90°F	95°F	100°F	105°F	110°F	115°F	120°F	125°F	130°F	135°F	140°F
5%	1.3	1.3	1.3	1.2	1.2	1.3	1.2	1.2	1.1	1.2	1.1	1.1	1.0	1.0	0.9
10%	2.5	2.5	2.4	2.3	2.3	2.3	2.3	2.3	2.2	2.2	2.1	2.1	2.0	2.0	1.9
15%	3.5	3.5	3.5	3.4	3.4	3.4	3.3	3.3	3.2	3.1	3.0	3.0	2.9	2.9	2.8
20%	4.5	4.5	4.4	4.3	4.3	4.3	4.2	4.1	4.0	4.0	3.9	3.8	3.7	3.7	3.6
25%	5.4	5.4	5.3	5.2	5.1	5.1	5.0	5.0	4.9	4.8	4.7	4.6	4.5	4.4	4.3
30%	6.2	6.2	6.1	6.0	5.9	5.9	5.8	5.7	5.6	5.5	5.4	5.3	5.2	5.1	5.0
35%	6.9	6.9	6.8	6.7	6.7	6.6	6.5	6.4	6.3	6.2	6.1	6.0	5.9	5.8	5.7
40%	7.7	7.7	7.6	7.5	7.4	7.3	7.2	7.1	7.0	6.9	6.8	6.7	6.6	6.4	6.3
45%	8.5	8.4	8.3	8.2	8.1	8.0	7.9	7.8	7.7	7.6	7.5	7.3	7.2	7.1	7.0
50%	9.2	9.2	9.1	9.0	8.9	8.8	8.7	8.5	8.4	8.3	8.2	8.0	7.9	7.8	7.7
55%	10.1	10.0	9.9	9.8	9.7	9.6	9.5	9.3	9.2	9.0	8.9	8.8	8.7	8.5	8.4
60%	11.0	10.9	10.8	10.6	10.5	10.4	10.3	10.1	10.0	9.8	9.7	9.5	9.4	9.2	9.1
65%	12.0	11.8	11.7	11.6	11.5	11.3	11.2	11.1	11.0	10.7	10.6	10.4	10.3	10.1	10.0
70%	13.1	13.0	12.9	12.7	12.6	12.4	12.3	12.1	12.0	11.8	11.7	11.4	11.3	11.1	11.0
75%	14.4	14.3	14.2	14.0	13.9	13.7	13.6	13.3	13.2	13.0	12.9	12.7	12.5	12.3	12.2
80%	16.0	15.8	15.7	15.5	15.4	15.2	15.1	14.8	14.7	14.5	14.4	14.2	14.0	13.7	13.6
85%	17.9	17.8	17.7	17.4	17.3	17.1	17.0	16.8	16.6	16.3	16.2	16.0	15.8	15.6	15.4
90%	20.5	20.3	20.2	20.0	19.8	19.6	19.5	19.2	19.1	18.7	18.6	18.4	18.2	17.9	17.7
95%	23.9	23.7	23.6	23.4	23.3	23.0	22.9	22.6	22.4	22.1	22.0	21.8	21.5	21.3	21.0
98%	26.6	26.4	26.3	26.1	26.0	25.7	25.6	25.3	25.2	24.8	24.7	24.4	24.	23.8	23.7

provided by restoration professionals. A topic of importance as an educator, researcher and consultant is to evaluate the role of vapor pressure and enthalpy differentials within the ambient air and within wood-based building materials. By understanding the thermodynamics involved in EMC, and the movement of moisture within wood, we find that vapor pressure and enthalpy differentials are key metrics that reveal the forces at work in drying efficiency.

The Second Law of Thermodynamics

The second law of thermodynamics states that in an isolated system, concentrated energy will disperse to lower energy. In regards to the restoration industry, the main focus is the movement of temperature and vapor pressure. High temperature moves to lower temperature and high vapor pressure moves to lower vapor pressure.

Key Psychrometric Dynamics: Vapor Pressure, Enthalpy and Differential Heat of Sorption

Psychrometric properties determine the energy content associated with the air and materials on a water loss. One such property is *vapor pressure*, which is measured in inches of mercury (in Hg). Vapor pressure is the pressure exerted by the molecules of a vapor on surrounding surfaces. High vapor pressure moves to low vapor pressure. High vapor pressure also is reduced by dehumidification.

Enthalpy (*h*) is a measurement of the air's total stored energy and is measured in British Thermal Units (BTUs) per pound of air. Enthalpy is comprised of two components which, when added together, determine the total energy value. The two components are "*sensible energy*" and "*latent energy*." Sensible energy deals with the temperature of the air. The sensible portion of enthalpy measures the energy it takes to raise the temperature of the air from 0°F to its current temperature. Sensible energy is the energy available to facilitate evaporation. The latent energy portion of enthalpy deals with the actual water in the air. The latent portion of enthalpy measures the energy it takes to evaporate the amount of water in the air (measured as grains per pound or the vapor pressure) at any given condition.

Chapter 36 of the *Handbook of Industrial Drying* is titled "Drying of Wood: Principles and Practices." In section 36.2.1.4, authors Patrick Perré and Roger Keey explain the significance of the differential heat of sorption in bound water below the fiber saturation point (FSP): "Sorbed water in the cell wall has a lower enthalpy than liquid water. However, contrary to other forms of water, such as solid, the enthalpy of bound water increases with increasing moisture content up to FSP. Above this value, the enthalpy of water in wood is essentially the same as that of liquid water" (Mujumdar 2006).

Based on the research provided by Perre and Keey, it can be deduced that by using current industry psychrometric equations regarding enthalpy, energy content, not only at saturation conditions (100% RH) but also at partial vapor pressures below saturation, can be determined. Other methods for determining enthalpy within wood are available; however, by using the current scientific measuring tools used in the restoration industry, we are able to use the metric of enthalpy of air to determine the energy value within the material.

Evaporation

Evaporation is an energy transfer process involving a change of state in water from the liquid form to vapor form. For water to convert from liquid to vapor, energy is added to increase the molecular movement. This breaks the attractive forces of the bonds that exist between neighboring water molecules. Evaporation is influenced by many factors, two of the most important are temperature and vapor pressure: The higher the temperature and drier the air, the faster materials will give up their moisture.

Equilibrium Moisture Content (EMC)

The moisture content of wood depends on the relative humidity and temperature of the air surrounding it. If wood remains long enough where the relative humidity and temperature remain constant, its moisture content will also become constant at a value known as Equilibrium Moisture Content, or EMC. Every combination of relative humidity and temperature has an associated EMC value (Simpson 1998). If the temperature and relative humidity of the surrounding air are known, a predictable EMC can be determined (Table 1). EMC is widely accepted and utilized in many industries, including the grain drying, food processing and wood kiln industries.

To understand the dynamics at work in an EMC condition, let's begin by identifying the role of water vapor pressure in the air and in hygroscopic materials.

> In *Transport Processes in Wood* John F. Siau writes, "Wood is a hygroscopic substance. It has the ability to take in or give off moisture in the form of vapor. Water contained in wood exerts vapor pressure of its own, which is determined by the maximum size of the capillaries filled with water at any time. If water vapor pressure in the ambient air is lower than vapor pressure within

> the wood, desorption takes place. The largest-sized capillaries, which are full of water at the time, empty first. Vapor pressure within the wood falls as water is successively contained in smaller capillaries. A stage is eventually reached where vapor pressure within the wood equals vapor pressure in the ambient air above the wood, and further desorption ceases. The amount of moisture that remains in the wood at this stage is in equilibrium with water vapor pressure in the ambient air, and is termed the equilibrium moisture content or EMC." (Siau 1984).

EMC calculators employ an equation to derive EMC. This article will not detail the equation, but readers will find excellent resources, including the equation used to determine EMC, by doing a web search of "equilibrium moisture content."

Capillary Forces and Diffusion

Moisture in wood will move from zones of high concentrations to zones of low concentrations. Thus, wood will dry first on the surface. Moisture from the interior then moves toward the surface and eventually evaporates when it reaches the surface.

The bulk of the water in wood occurs in two forms: It occurs as liquid "free" water in the cell cavities and as "bound" water in the cell walls. In addition, water vapor is present in the air spaces in the cell cavities.

Moisture moves in wood by two mechanisms and these are related to the type of water involved. Liquid free water moves in response to capillary forces. Bound water and water vapor move by *diffusion* in response to a partial vapor pressure gradient.

In *Drying Small Quantities of Hardwood Lumber—Understanding the Effects of Moisture on Wood*, Daniel Cassens writes,

> "During the drying process, several forces may act simultaneously to move water:
>
> 1. Capillary action causes free water to flow, for the most part, through cell cavities and small openings in the cell walls.
>
> 2. Differences in relative humidity in the wood causes water vapor to move through various passageways by diffusion.
>
> 3. Differences in moisture content move the bound water through the small passageways in the cell wall by diffusion.
>
> 4. Evaporation of water from the surface sets up capillary forces which exert a pull on the free water in the zones of wood beneath the surface, resulting in a flow. This process is similar to the movement of water in a wick.
>
> 5. Movement of moisture by diffusion results from differences in the relative humidity and moisture content between the surface and the interior or between any two zones of the wood. Moisture in wood moves to the surface by simultaneous diffusion of vapor and bound water. In comparison with capillary movement, diffusion is a slow process." (Cassens 1992)

The Significance of Fiber Saturation Point in Drying

In an introduction to the 1964 instructional movie, *The Mechanism of Moisture Movement in Wood*, G. L. Comstock states, "A concept which is important in the movement of moisture is the fiber saturation point. This is defined as the moisture content at which the cell walls are saturated with water and no liquid water is present in the cell cavity." (Comstock 1964)

To illustrate fiber saturation point, first envision an open container of water. Next picture a piece of cardboard rolled up and placed in the container of water. Finally, imagine the container of water poured out into a sink. Once all the excess water has been released down the drain, the cardboard roughly approximates wood at the fiber saturation point.

The fiber saturation point of wood is approximately 25-30%. This percentage varies slightly by type and ambient temperature, but is a good rule of thumb.

Evaporation and Water Movement Rates in Wood

The rate at which moisture moves in wood depends on three things:

1) the relative humidity of the surrounding air,
2) the steepness of the moisture gradient (i.e., the difference in moisture content between the surface and the inner portion of a section of wood), and
3) the temperature of the wood.

Lower relative humidity of the ambient air increases capillary flow of the free water and stimulates diffusion of the bound water by lowering the moisture content at the surface. Similarly, the higher the temperature of the wood, the faster moisture will move from the wetter interior to the drier surface, thus the steeper the moisture gradient (USDA 1987).

As previously noted, water moves through wood in in three distinct ways:

- *Capillary flow* (also called wick effect)- This occurs in wood that has free water in the cell cavities and continues until the wood reaches the fiber saturation point. Evaporation of water from the surface sets up capillary forces which exert a pull on the free water in the zones of wood beneath the surface, resulting in a flow. This process is similar to the movement of water in a wick.

- *Diffusion as hygroscopic (bound) water* in the cell walls- This water is below the fiber saturation point. It will be about 25-30% of the overall moisture content. If the cells of wood are wetter than this, there will be free water in the cell cavities.

- *Diffusion as water vapor* through the air in the cells and through the openings in the cell walls- This method takes place in the part of the wood that has no free water and thus is below the fiber-saturation point.

In vapor movement, water moves in gaseous form across cell cavities and through openings in the cell wall such as in the pit membranes. Additionally, some water vapor moves across cell cavities, deposits on cell walls as bound water, is absorbed through the cell walls to the surface on the other side, then repeats the process until it reaches the surface of the wood and evaporates.

The volume of water that moves in each of these ways will depend on several factors. A moisture difference in a board that is nearly wet in one zone and very dry in another will tend to give the greatest moving force at a given temperature. This is because the vapor pressure differential will be greater between the wet and dry zones.

If the drying temperature is raised, the number of water molecules that evaporate into a cell cavity will increase, as will the vapor pressure. Consequently, the vapor pressure differential between the wet zone and the dry zone will be greater and the drying rate will increase as a greater amount of water vapor moves to the surface zone where the amount of water vapor in the cell cavities is kept low by the lower relative humidity of the outside air. Vapor movement in wood is very important below the fiber-saturation point — more important than movement of bound water within the cell wall — and it becomes more important as the moisture content decreases (Erickson 1954).

In summary, moisture in wood-based building materials will move from zones of high concentrations to zones of low concentrations. Thus, wood will dry first on the surface. Moisture from inside the board then moves toward the surface and eventually evaporates. During the drying process, several forces may act simultaneously to move water. These forces include: 1) capillary flow, which causes free water to flow through cell cavities and small openings in the cell wall; 2) differences in vapor pressure and relative humidity in the wood, which causes water vapor to move through various passageways by diffusion; 3) differences in moisture content, and 4) the temperature of the wood.

Time — The Critical Factor for Restorative Drying

Now that there is a clear understanding of how the mechanisms, forces and factors work within the EMC model, metrics can be applied to help determine the efficiency or rate of potential water removal from water-damaged wood-based building products.

The two most recurring questions pertaining to drying out water-damaged structures are from two materially interested parties. They both involve time. The contractor asks, ”Why is this job taking so long?” The insurance claims adjuster asks, “Why did this job take so long?”

How can EMC help answer these two questions which both pertain to time, one of the most critical issues in structural drying?

Note that the EMC chart (Table 1) reveals that the same moisture content can be achieved at various conditions. For example, as the chart shows, a 6.2% EMC can be achieved at 70ºF, 30%RH and also at 115ºF, 35%RH. What the EMC model does not address is which condition will achieve the 6.2% moisture content fastest. That question is addressed by Energy Transfer Rate (ETR).

The Foundation of ETR: Drying Fundamentals, Assessment and Documentation

When evaluating water-damaged structures, many considerations go into developing a drying strategy. Before the drying process is started, items such as source of water intrusion, type of water involved, affected building materials, physical water extraction, dehumidification requirements, quantity of air movers, negative air machines, demolition, and others have to be addressed. Throughout the drying process, the restoration contractor assesses the performance of the system and based on this ongoing assessment adjusts strategy as needed.

Accurate documentation is critical when assessing the efficiency of a drying system. Two key documents to evaluate the progress and provide validation that the system is working are the “daily psychrometric sheet” and the “material moisture map.”

The daily psychrometric sheet provides information about the ambient air in the affected area, outside, and in adjacent unaffected areas. The information includes temperature, relative humidity, grains per pound of air (gpp), and water vapor pressure measured in inches of mercury (in Hg). This data provides critical information concerning the environmental conditions directly correlated to the efficiency of the drying system. Grain depressions are also calculated to determine if the dehumidifier is removing water vapor from the drying chamber, thus lowering the gpp/vapor pressure. Cubic footage of the affected area is also recorded to determine initial dehumidification requirements.

The material moisture map validates that the system is working by showing a reduction in the moisture content of the affected building materials either by percentage (% MC) or relative moisture content.

Energy Transfer Rate (ETR) — The Missing Link

Time is critical for effective restorative drying. Once the drying system is in place, the goal is to evaporate water from the wet building materials back to a dry standard in an efficient, controlled and measurable manner. How is the drying system measured to determine efficiency and what type data is needed?

As previously described, vapor pressure and enthalpy differentials are the key metrics driving evaporation in wood. In order to determine the vapor pressure and enthalpy differentials, following is the data needed and the tools required to obtain it:

- Temperature of air (thermo-hygrometer)
- Relative humidity of air (thermo-hygrometer)
- Temperature of materials (infrared laser thermometer)
- Moisture content (%MC) of materials (invasive/pin-type moisture meter)

If we know the temperature of the wood and the actual moisture content in the wood by weight, we can derive the corresponding relative humidity within the wood. If we have the temperature of the wood and the equilibrium relative humidity of the wood, then we are able to derive the vapor pressure within the wood (Larsen 2010).

In order to test the postulated theory that vapor pressure and enthalpy differentials are the keys to maximizing evaporation rates in wood, the author developed an ETR algorithm to determine the vapor pressure and enthalpy of the wood, based on the material temperature and moisture content, and tested it against variable sets (Table 2). This test verified the accuracy of the algorithm.

Next, experimental testing was done. Prior to testing, red oak and SPF wood samples were submerged in water for 24 hours. Prior to drying, the temperature and moisture content of all samples were measured using a laser thermometer and an invasive/pin-type moisture meter respectively, and vapor pressure and enthalpy were calculated according to the author’s algorithm. Drying chambers were established both with and without airflow (airflow was provided by a 3,000+ cfm air mover).

The tests consisted of three different ambient air drying conditions:

Test one: 70ºF, 35% RH, vapor pressure (inHg) 0.26, enthalpy (h) 22.5

Test two: 90ºF, 25% RH, vapor pressure (inHg) 0.35, enthalpy (h) 29.5

Test three: 115ºF, 18% RH, vapor pressure (inHg) 0.52, enthalpy (h) 39.3

The tests were timed: 24 hours. At the end of the test period, the temperature and moisture content of the wood and ambient air were again measured and vapor pressure and enthalpy calculated. Without exception, the test results validated the postulated theory that greater vapor pressure and enthalpy differentials result in greater rates of evaporation.

Further, it was noted that contrary to conventional drying theory, lower air grain levels were not an accurate predictor of drying efficiency; in fact, there was an inverse correlation between moisture content of the wood and grains of moisture in the air.

Figure 1 details key findings from the tests. Note: For simplicity, averages are used for each of the four samples in each test (SPF with airflow, SPF no airflow, oak with airflow, oak no airflow). In all three tests, significant moisture content reduction was realized: 44% in test one, 56% in test two, 64% in test three. The highest reduction correlated with the highest vapor pressure and enthalpy differential, the middle reduction with the middle differential, and the lowest reduction with the lowest differential.

Equilibrium Moisture Content vs. Psychrometric Conditions
Energy Transfer Rate Deltas Δ inHg, Enthalpy, %MC

Materials		V.P.	Enthalpy	Environment		V.P.	Enthalpy		Δ	Δ	Δ
Temp	% MC	inHg	BTU's	Temp	RH	inHg	BTU's	% EMC	inHg	Enthalpy	% EMC
70	6.2	0.22	21.7	70	30	0.22	21.7	6.2	0.00	0.0	0.0
75	7.6	0.35	25.8	75	40	0.35	25.8	7.6	0.00	0.0	0.0
80	8.3	0.47	29.6	80	45	0.47	29.6	8.3	0.00	0.0	0.0
85	9.0	0.61	34.0	85	50	0.61	34.0	9.0	0.00	0.0	0.0
90	5.1	0.35	29.5	90	25	0.35	29.5	5.1	0.00	0.0	0.0
95	2.3	0.16	26.5	95	10	0.16	26.5	2.3	0.00	0.0	0.0
100	7.2	0.76	41.5	100	40	0.76	41.5	7.2	0.00	0.0	0.0
105	4.1	0.45	35.2	105	20	0.45	35.2	4.1	0.00	0.0	0.0
110	1.1	0.13	29.3	110	5	0.13	29.3	1.1	0.00	0.0	0.0
115	3.5	0.51	38.9	115	17	0.51	38.9	3.5	0.00	0.0	0.0

Table 2. At various temperatures and relative humidity values, the delta (Δ) of inHg, enthalpy and % EMC (right three columns) are in balance. For example, with an environmental condition of 70° and 30% RH the vapor pressure (*vp*) and enthalpy (*h*) of both the air and wood materials are at (*vp*) 0.22 and (*h*) 21.7. There is no differential between the vapor pressure and the enthalpy and the materials are not gaining or losing moisture, thus an equilibrium state has been reached. By assigning a relative humidity value to the materials based on percentage of moisture content (%MC) and the temperature of the material, the vapor pressure and enthalpy metrics can be determined.

ETR does not measure the actual movement of water out of materials, only moisture meters determine if and when there is a reduction in moisture content. Numerous factors that impact the rate that water is removed from the materials — including density, permeance, airflow, vapor barriers — are not addressed in this work. However, all else being equal, the greater the differential in vapor pressure and enthalpy, the stronger the force for water to be released..

Conclusions

This paper is the result of a study on the role of vapor pressure and enthalpy in drying water-damaged structures containing wood-based products. The use of the EMC formula provided a foundational base from which the ETR model was developed. Research from within the wood-drying industry provided invaluable insights into the nature of hygroscopic materials and moisture transport in wood and related properties.

The ETR model used in this study was originally developed in 2011 and remains a work in progress. This model is not merely theoretical, it has been used in real-world applications of drying-out water-damaged structures. Real-world application is the true proving ground.

On average, the fiber saturation point of wood-based products is approximately 25-30% moisture content. Below fiber saturation point, wood-based products are hygroscopic in nature and transport moisture via vapor. Determining vapor pressure within these hygroscopic materials below fiber saturation using surface temperature and saturation vapor pressure (100% RH) is an inaccurate measurement and is contrary to the EMC

Energy Transfer Rate - wood samples of SPF and Red Oak submerged in water for a 24 hour period prior to testing. 3 different conditions and impact on materials.

	Materials		V.P.	Enthalp	Environment		V.P.	Enthalpy		Δ	Δ	Δ
	Temp	% MC	inHg	BTU's	Temp	RH	inHg	BTU's	% EMC	inHg	Enthalpy	% EMC
start	78	23.7	0.91	39.6	70	35	0.26	22.5	6.9	0.65	17.0	16.8
24 HRS	70	13.2	0.52	28.4	70	35	0.26	22.5	6.9	0.27	5.9	6.3
start	78	24.2	0.91	39.6	90	25	0.35	29.5	5.1	0.56	10.1	19.1
24 HRS	90	10.5	0.83	40.6	90	25	0.35	29.5	5.1	0.48	11.1	5.4
start	78	26.5	0.94	40.3	115	18	0.52	39.3	3.5	0.41	0.9	23.0
24 HRS	115	9.5	1.71	67.4	115	18	0.52	39.3	3.5	1.19	28.1	6.0

	Materials 0 Hours		24 Hours		
Test 1	Temp	%MC	Temp	%MC	Δ
SPF w/ Airflow	78	21.8	70	13.8	37%
SPF	78	21.6	70	13.4	38%
Oak w/ Airflow	78	25.3	70	12.5	51%
Oak	78	26.2	70	13.1	50%
Average	78	23.7	70	13.2	44%

Air: 70F/38 GPP

	Materials 0 Hours		24 Hours		
Test 2	Temp	%MC	Temp	%MC	Δ
SPF w/ Airflow	78	22.8	90	12.0	47%
SPF	78	24.1	90	11.8	51%
Oak w/ Airflow	78	25.2	90	8.4	67%
Oak	78	24.8	90	9.7	61%
Average	78	24.2	90	10.5	56%

Air: 90F/52 GPP

	Materials 0 Hours		24 Hours		
Test 3	Temp	%MC	Temp	%MC	Δ
SPF w/ Airflow	78	24.7	115	10.4	58%
SPF	78	28.1	115	10.5	63%
Oak w/ Airflow	78	27.2	115	7.9	71%
Oak	78	26.0	115	9.2	65%
Average	78	26.5	115	9.5	64%

Air: 115F/77 GPP

Test 1 - MC% of 13.2% and reduction of 44%, Δ .27 inHg, Enthalpy Δ 5.9
Test 2 - MC% of 10.5% and reduction of 56% Δ .48 inHg, Enthalpy Δ 11.1
Test 3 - MC% of 9.5% and reduction of 64% Δ 1.19 inHg, Enthalpy Δ 28.1

Airflow was provided via 3,000+ cfm air mover placed 6' from material.

Figure 1. Energy Transfer Rate Experimental Results

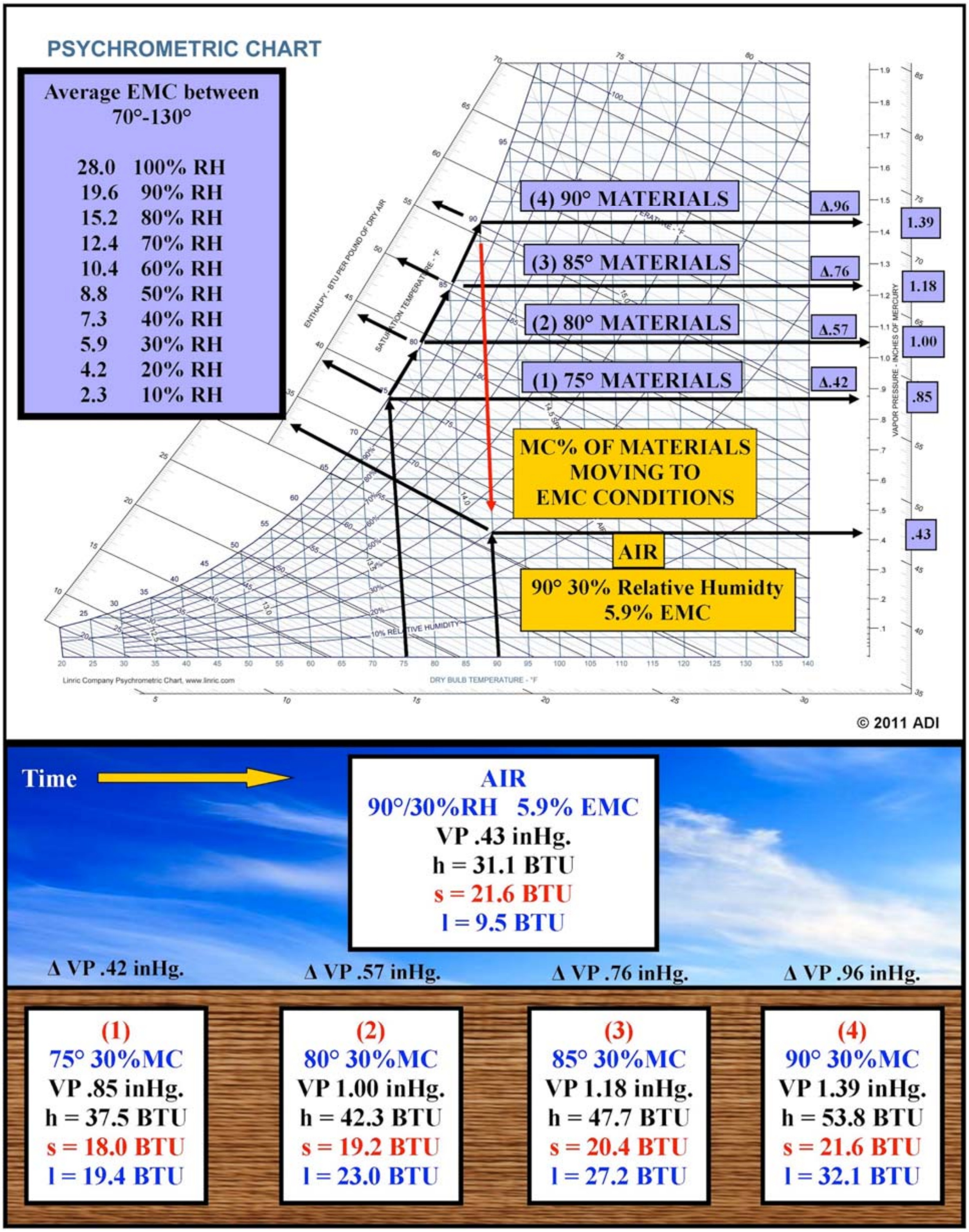

Figure 2. Process of Energy Transfer Rate (ETR) applied to the psychrometric chart and the impact on wet, wood-based building materials at fiber saturation conditions. Note the application of the second law of thermodynamics of high energy (sensible and latent) moving to low energy. The sensible energy of the air moves to the cooler wet materials resulting in an increase of vapor pressure and enthalpy within the materials. As this transfer is taking place, the higher vapor pressure and enthalpy within the materials will move to the lower vapor pressure and enthalpy in the air. As the system continues to seek equilibrium, moisture content is reduced until EMC conditions are reached.

chart. When EMC conditions exist, there is no free or liquid water present within wood-based products. Therefore, the moisture remaining within the materials has a relative vapor pressure and not a saturated vapor pressure. Based on these findings, vapor pressure and enthalpy values can be determined within the materials.

The second law of thermodynamics can be measured to determine drying efficiency of water-damaged buildings. Laboratory and real-world application of ETR have proven that the larger the differentials of vapor pressure and enthalpy between materials and the ambient air, the faster the building dries. There is a disparity between current structural drying practices and the value that the EMC chart can provide to our industry. The humidity ratio or grains per pound (gpp) was found to be an ineffective predictor of structural drying performance because the main purpose of the humidity ratio (gpp) is to measure dehumidifier performance. During the testing reported in this paper, industry standard boilerplate sizing for dehumidification was not applied.

The transfer of energy is the driving force in evaporation, not how dry the air is.

Structural drying efficiency can be measured, validated, predicted and repeated by understanding the two key metrics located on the psychrometric chart — vapor pressure and enthalpy. These two measurements have been integrated into wood-based building products and a solid foundation is in place to challenge our industry towards the future.

Recommendations for future research

The role of vapor pressure and enthalpy in different types of building materials, such as sheetrock, concrete, tile, and carpet, is fertile ground for additional research. Research in the area of vapor pressure and enthalpy differential benchmarks for determining drying rates, based on the type and complexity of building materials, will also be fruitful. By understanding the dynamics of moisture movement within different materials and assemblies, industry standards can be determined based on quantitative data. Finally, an examination of industry dehumidification standards and practices would be useful in ensuring the most effective use of these important tools.

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Jerry Blaylock, WRT, ASD, CSDS is owner of American Drying Institute, LLC in Morristown, TN 37814. jerryblaylock@hotmail.com

Fundamentals of Wildland Fire Retardant Removal from Exterior Surfaces

Jeff Bishop and Cindy Linden

Introduction

Fire retardants are designed to suppress and decrease the intensity of wildland fires, and to protect property when wild fires threaten. Fire retardants are evaluated by the USDA Forest Service's Wildland Fire Chemical Systems (WFCS) subgroup for testing, use and monitoring. The primary products are formulated under the trade name Phos-Chek®, and are currently being used in California by the U.S. Forestry Service to decrease the intensity of wildland fires. This allows ground fire crews to work more safely by containing the wildfires.

Fire retardants are extremely useful in suppressing wildfires so that fire fighting ground crews can access burning areas to complete the job of extinguishing the fire. These products have been used since the late 1950s. Unfortunately, their use can create residual problems for property owners, although those problems pale in comparison with the alternative of failing to suppress the fire: that being total property destruction.

Product Types and Application

According to the National Fire Protection Association (NFPA), there are three general types of products used as Class A fire retardants:

1. **Long-term Retardants:** These typically are applied from fixed or rotary-wing aircraft. While there are a number of products that have been used as fire retardants in the past, Phos-Chek®, manufactured by ICL Performance Products LP, is the predominant brand used for long-term fire retardation today. Regarding the Phos-Chek® products, including 259F, 259R, 259W, D-75F and D-75R, the USDA Forest Service WFCS web site specifies:

   a. Long-term retardants basically contain about 85 percent water, 10 percent fertilizer and 5 percent other minor ingredients, such as colorant (usually iron oxide — rust — or fugitive dye that breaks down with UV light exposure and are less likely to discolor surfaces), thickener (natural gum and clay), corrosion inhibitors, stabilizers and bactericides.

   b. At this time, Phos-Chek® 259F and D-75F are the long-term fire retardants being dropped from aircraft on the California wildland fires. The chemical code "F" means they contain a synthetic color resin; "R" means the retardant contains iron oxide for coloration; and "W" means the retardant is uncolored, actually appearing somewhat white or light beige. According to Chuck George, retired Project Leader for the USDA Forest Service Government Center in Missoula, MT, long-term fire retardants are colored red for higher visibility over the drop zone, and in time, they are designed to fade with exposure to UV light

(sunlight). Of course, it is this red colorant that can present problems for professional cleaners and restorers.

c. The concentration of fertilizer used in long-term retardants is what provides their fire-suppressing capabilities. Due to this heavier concentration, it is important to use caution and good judgment when cleaning up the residual effects of long-term retardants.

d. The pH of chemical components in fire retardants can be as low as one; however, product formulations can be buffered to a pH of 5.5 to 7.5.

2. **Foams (Phos-Chek® WD881):** These are typically applied from ground equipment. Rarely are they dropped from aircraft as long-term retardants. Basically, foams are concentrated dish detergents: 99 percent water, and 1 percent surfactant, foaming agents, corrosion agents and dispersants. Foams are sprayed onto structures. Since fire retardant foams are composed of slightly more concentrated household dish-type detergent with no dye, they can be removed with thorough rinsing using copious water.

3. **Gels: (Phos-Chek® AquaGel K; Thermo-Gel® 200L):** Like foams, these typically are applied using ground equipment. Like foams, rarely are gels dropped from aircraft as long-term retardants. Gels are water enhancers, consisting of 95-98 percent water, 2-5 percent thickeners, stabilizers and other minor ingredients. They may consist of proprietary blends of polymers, hydrocarbons, surfactants and water, with a slightly acid pH. Gels can be sprayed or spread onto structures. Gels protect structures from fire longer than foams, and for several hours versus minutes with water only.

   According to Cecilia Johnson, USDA Forest Service, Project Leader for WFCS, gels are formulated as a super-absorbent polymer (like that used in disposable baby diapers or surgical bandages that keep wounds moist) that is a thickened, water-based solution. Gels come in two forms that may be identified by color (used for high visibility):

- Orange (or dark orange if contaminated by long-term fire retardant drops), or clear gels, can be removed by rinsing with water or citric acid. In some cases, copious water-rinsing alone removes the residue.
- Blue-colored gel is mixed with ingredients similar to mineral or vegetable oil (used as suspension agents) and water, and must be treated as such. These suspension agents make cleaning somewhat more challenging, in that oil components must be emulsified for efficient removal from surfaces where gels are applied.

Cleaning Procedures

This paper is confined to procedures for cleaning building exterior surfaces. Interior surfaces that have experienced infiltration of long-term fire retardants should be cleaned using appropriate dry and wet cleaning techniques commonly used in fire restoration work.

At no time should chlorine bleach or chlorine bleach-based products be used in retardant removal. Using chlorine-based products could cause harmful and explosive gases.

Now, let's discuss long-term retardants as they pertain to cleanup by professional cleaners and restorers. First, we need to remember that 85 percent of the long-term retardant, the most common exterior building contaminant, is water, which, by itself, is safe, and of course water will evaporate. Second, we need to consider that ammonium compounds (ammonium phosphate, diammonium phosphate) can cause eye irritation, while causing cuts, scratches, chapped or sunburned skin to sting. Retardants are also known to cause dry skin; therefore, fire retardant that comes in contact with skin should be washed thoroughly with soap and water, followed by using a good quality skin cream to minimize drying and chapping.

Last, the minor ingredient used for color is iron oxide, otherwise known as rust; or more commonly today, other fugitive dye is used. Colorants may discolor wood or metal, particularly oxidized metal or painted surfaces. This red color, especially if from iron oxide, can be very stubborn to remove and should be washed off as soon as possible. Most fugitive red dyes are designed to degrade with exposure to ultraviolet (sun) light.

Improper power washing may force the red colorant in long-term fire retardants into wood and other porous materials, resulting in permanent staining. Therefore, to achieve maximum cleaning effectiveness on exterior surfaces contacted by long-term fire retardant — particularly durable, colorfast exterior surfaces that are showing staining or white residues (e.g., brick, stone, vinyl or aluminum siding, painted wood) — specific cleaning agents and procedures should be considered. If long-term retardants colored with iron oxide (rust) are encountered, restorers should pay special attention to galvanized materials. Once protective zinc coatings are removed, underlying materials are subjected to oxidizing or rusting. In this case, appropriate reapplication of a protective coating would be recommended.

Professional restoration techniques that should be considered when removing long-term gel or foam fire retardants from exterior structural surfaces include, but are not limited to:

1. Restorers should wear appropriate safety equipment (gloves, goggles, respirators, protective clothing). Note that fire retardant gel residues on walkways, patios or pool decks may become slippery when wet during cleaning. Caution to avoid slip-fall injuries is advised.
2. Flora should be protected from chemical cleaners by covering them with plastic; they should be rinsed thoroughly with water after cleaning processes have been completed.
3. Hand cleaning (prespray, hand agitate, rinse) may be required to remove fire retardant from window and door claddings, especially if paint or finishes have deteriorated or oxidized, making them more absorbent and susceptible to staining. The same may be necessary for other exterior finish materials (e.g., trim, gutters, downspouts). Window glass with baked-on *foam or long-term retardant* will have to be hand-scraped and cleaned using glass cleaner, or nonchlorinated tub-and-tile cleaners, which typically are acidic.
4. Restorers should ensure that windows and doors are sealed, or covered with plastic, to prevent moisture intrusion and corresponding damage within the structure.
5. A biodegradable general-purpose cleaner or pressure-washing compound, mixed according to manufacturer directions, should be spray-applied to exterior veneers (e.g., walls) working from bottom-to-top. Dry-solvent additives (propylene glycol), which are found in many household (kitchen) cleaning agents, may enhance emulsification of oils used in blue or clear gel-type fire retardants. Prespraying is a critical procedure if contaminant is to be fully dissolved or emulsified, and if staining compounds are to be successfully suspended rather than absorbed into porous building materials.
6. After spray applying, the cleaning solution should be uniformly distributed with a soft-bristled brush, followed by a few minutes of dwell time. The preconditioning solution should not be allowed to dry completely before pressure cleaning.
7. The wall should be pressure washed, working from *bottom to top*, always progressing upward into fresh detergent for maximum chemical effectiveness and soil suspension. Hot water speeds chemical reactions and improves cleaning effectiveness. Note that older finishes on exterior veneers may be damaged by aggressive pressure cleaning.
8. Restorers should flush or rinse walls from *top to bottom* to ensure removal of cleaning and contaminant residues. Then, they should inspect, respray and reclean areas that show residual staining or contaminant residue.
9. Restorers should ensure that no water is pooled, which may attract thirsty animals. Fill puddles with soil or sand as required.
10. Restorers may follow-up abrasive cleaning with blast media (sand, sponge, dry ice) may be required to remove (abrade away) residual staining from some surfaces, such as brick, stucco, stone, mortar or even wood.

11. Finally, restorers should remove plastic from foundation flora; rinse and water plants with copious water to dilute and remove residual contaminant or cleaning solution.
12. Surfaces that do not respond to cleaning may require recoating or replacement in some cases.

Additional Considerations

According to SDSs, upon decomposition, Class A fire retardants produce the byproducts carbon monoxide, partially oxidized hydrocarbons, smoke and soot. Class A retardants, when disposed, are not considered a hazardous waste, as defined by the Resource Conservation and Recovery Act (RCRA), 40 CFR 261, and may be transported safely.

Again, to avoid possible harm to pets or other animals, restorers should ensure that water exposed to retardants not be allowed to puddle or stand. It should be soaked up with sand, soil or other absorbents to avoid ingestion by animals. Pets and animals exposed to residues of the fire retardant should be shampooed and rinsed thoroughly, keeping in mind that retardants can dry their skin. If an animal appears sick from drinking from puddles or standing water, owners should seek medical attention and advise the veterinarian that the animal may have ingested a detergent or fertilizer-based product.

Cars exposed to long-term fire retardant residues should be quickly and thoroughly washed. Polishing can remove remaining staining and residue.

Inevitably homeowners will ask professionals about restoring their foliage and plants that have long-term fire retardant on them. Rainwater quickly dilutes the residual retardant, and again, these decomposed components and byproducts are not considered a hazardous waste.

As a point of interest, since the fertilizer concentration in long-term fire retardant is higher than that sold at garden stores, it may cause leaf burn. According to Chuck George, “It is recommended that, with copious water to dilute the concentration, greenery will fully recover.” Plants may appear to be dead after contact, although in most cases they will recover and grow back in one to two months. Some aesthetically valuable vegetation may not survive exposure. When garden produce (e.g., fruits and vegetables) has been exposed to long-term fire retardant, as with all produce, it should be washed thoroughly before being consumed.

The Bottom Line

The byproducts from diluted long-term fire retardants are less hazardous than smoke and soot, and are not considered hazardous waste. Effective cleaning and restoration of exterior surfaces exposed to them can be successfully accomplished using the cleaning processes previously described.

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(406) 329-3900; www.fs.fed.us/rm/fire/wfcs/

Phos-Chek® Brand Products (U.S.)

ICL-Performance Products LP

810 E. Main Street; Ontario, CA 91761

800-682-3626; www.phoschek.com

Jeff Bishop is an IICRC-approved instructor in carpet cleaning, upholstery cleaning, rug cleaning, carpet inspecting, fire and smoke restoration, water damage restoration, and odor restoration. jeff@cleancareseminars.net.

Cindy Linden is Executive Administrator of Clean Care Seminars, Inc. cindy@cleancareseminars.net.