Case Report

Irritation and Clean-up Methods Following Installation of Cellulose Attic Insulation in one NJ Home

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ABSTRACT

This article summarizes a case report of a NJ homeowner who recently participated in an energy efficiency project involving weatherization and sealing of an attic, followed by installation of a recycled newsprint-based cellulose blown-in insulation product, which resulted in respiratory distress and eye, nose, throat, and skin irritation among occupants of the home. Impacts to the home, clean-up efforts, and the ultimate resolution of the problem are described, along with the building science, industrial hygiene, and toxicology principles that help explain the challenges in resolving such symptoms. This information is presented for the purpose of alerting homeowners and energy conservation and weatherization professionals to the importance and potential of planning insulation projects using techniques that reduce the potential for fugitive emissions of dust into the home.

INTRODUCTION

As the increase in electricity demand over recent years has not been met with a commensurate increase in electricity supply, several states and the federal government have increased efforts to reduce energy use in residential, commercial, and manufacturing facilities. According to the NJ Master Energy Plan, electricity generation capacity has increased an average of only 0.71% per year between 2002 and 2007, and peak electricity demand is expected to grow at approximately 1.75% per year between 2008 and 2018 [NJ Energy Master Plan http://nj.gov/emp/docs/pdf/081022_emp.pdf]. Electricity rates have more than doubled between 2002 and 2008, and further increases are expected as the disparity between electricity supply and demand increases. These concerns, combined with the release of greenhouse gases that increase the potential for global warming, have lead to a New Jersey goal of reducing greenhouse gas emissions by 20% by the year 2020. While some of this reduction in greenhouse emissions may be met by improving the efficiency and cleanliness of electricity generation, NJ's #1 approach toward meeting these reductions is through "maximization of energy conservation and energy efficiency," including:

- Considering whole building approaches to energy efficiency.
- Increasing energy efficiency of new buildings by 30% relative to that of existing buildings.
- Enhancing energy efficiency of new appliances beginning in 2009.
- Increasing public awareness of the importance of energy conservation and energy efficiency upgrades.

According to the The Rutgers University Center for Green Buildings, in their recently released NJ Green Home Remodeling Guidelines, residential buildings account for 22% of total energy consumed in the United States. A typical home emits almost 9,000 pounds of carbon dioxide per person per year, roughly 17% of the nation's carbon dioxide emissions. Moreover, Americans spend 90% of their time indoors, where concentrations of pollutants are often much higher than outside, making "green" considerations in the residential sector important for both the environment and human health [Rutgers Center for Green Buildings http://www.greenbuildingrutgers.us/projects.asp?Level2ItemID=52].

With the increased public awareness of the need to reduce energy consumption in homes, many homeowners are increasingly looking at their energy efficiency and taking steps to improve efficiency and reduce energy costs related to heating and cooling. Many states, like New Jersey, have clean energy programs to incentivize homeowners to arrange for low-cost energy audits of their homes, perform weatherization services, and install energy saving devices such as energy efficient boilers, hot water heaters, heat exchangers, insulation, windows, solar panels, or other energy saving devices. According to the NJ Clean Energy Program, approximately 577,000,000 kWh of electricity savings and 4,900,000 therms of annual natural gas savings have resulted from energy conservation efforts implemented under the program in 2008 [NJ Clean Energy Program http://www.njcleanenergy.com/main/about-njcep/program-savings-and-benefits/program-savings-and-benefits].

CASE SUMMARY

The home at which this incident occurred is a split level home of approximately 2,500 square feet in the central NJ area. The home has two separate attics of approximately 500 ft^2, each of which had approximately 10 inches of fiberglass batt insulation (R-30). Gable vents for the home had been sealed several years prior to this project. Access to each attic was via attic hatch doors with pull-down stairs.

According to reports from the homeowners, during the summer of 2009 a contractor sealed openings in eaves, soffits, and other areas of the attic, then utilized flexible hoses to blow a dry cellulose-based recycled newsprint insulation product into both attics on top of the existing fiberglass insulation. A review of the material safety data sheet for the product indicated that it contained approximately 85% by weight of recycled newsprint and up to 15% by weight of boric acid, ammonium sulfate, mono-ammonium phosphate, and other compounds (likely as rodent inhibitors and fire suppressants). Approximately 1200 pounds of insulation were blown into the two attic spaces combined, producing several inches of additional insulation on top of the existing fiberglass insulation. Upon completion of the installation, flexible return ductwork for the forced-air heating and air conditioning system was observed to be partially

buried within the insulation product.

During the installation process, the homeowners reported that a large cloud of dust from the insulation entered the home via the hatch doors and coated the entire home, including horizontal surfaces of furniture, bedding, flooring, carpets, and draperies. Eye, mouth, skin, and respiratory irritation, along with a bitter taste within the mouth were associated with the increased dust levels within the home. In response to this, the contractor immediately hired a local cleaning service to vacuum and wipe all surfaces of the home to remove dust residues. Despite repeated cleaning attempts by the service and homeowners, the home continued to display settled dusts on horizontal surfaces throughout the home for a period of several weeks following the initial cleaning. Based on the irritation, bitter taste, and continued settled dusts, the homeowners contracted a Certified Industrial Hygienist (CIH) to inspect the home and recommend cleanup procedures that would be expected to return the home to a normal condition.

The CIH inspected the home in mid-August 2009 and conducted real-time air monitoring for particulate matter, using a laser particle counter (for particles larger than 1 micron in diameter). Air sampling was conducted to be microscopically analyzed at 20 to 40X magnification for cellulose particles within the home, as well as outdoors for comparison. Surface samples for optical microscopy were also collected from representative horizontal surfaces throughout the home.

Visual inspection findings revealed numerous indications of significant dust accumulations on surfaces of wooden furniture within the living room, master bedroom, and other locations. There was an immediate sensation of dusty air, a bitter taste in the mouth, and throat irritation detectable by the CIH.

Air monitoring findings revealed that outdoor air levels of dust particulate matter >1 micron ranged between 3,600 and 8,000 particles per cubic meter of air, with an average of 5,720 particles per cubic foot (partcles/ft^3). Air levels within the kitchen, which contained all hard surfaces, averaged 7,900 particles/ft^3. Air levels within all other indoor living space locations, which were carpeted and contained upholstery, etc., averaged from 11,300 to 19,200 particles per cubic foot, approximately 2-3 times the outdoor dust level. Air levels of dust particles within both attics were also comparable to outdoors, at 2,900 and 5,800 particles/ft^3.

Air sampling results revealed that cellulose content of outdoor air comprised approximately 13% of the sample, superseded by carbonaceous particles, mineral particles, and mold spores (considered normal). Cellulose content of all indoor air samples was 2 to 3 times higher than that of outdoors, ranging from 23% to 36%, with very low levels of carbonaceous, mineral, and mold spore content. The average particle size of the indoor air cellulose particles was 4-5 microns (μ) in diameter and approximately 50-60μ in length (aspect ratio approximately 10:1), while outdoor cellulose content averaged approximately 2.5μ in width and 12.25μ in length (aspect ratio approximately 5:1). Based on this, it was the laboratory's conclusion that the type of cellulose collected from within the home was significantly smaller in diameter and length than cellulose measured in outdoor reference locations.

Surface sampling results indicated that the cellulose content of surface dust from the master bedroom dresser and living room sofa table was comparable to the air distribution of cellulose at 23%, suggesting that airborne cellulose contamination was being deposited and re-suspended on and from horizontal surfaces throughout the home.

Based on these findings, it was concluded that the elevated air levels of cellulose dust associated with the insulation application remained within the air of the home. It was recommended that the air and surfaces of the home be cleaned with HEPA filtration-equipped vacuums and air scrubbers that filter to a minimum efficiency of 99.9% at a particle size of 0.3μ. It was recommended that all ceiling, wall, floor, and contents surfaces be HEPA vacuumed and/or damp wiped to remove surface dust contamination in a manner that would not re-suspend that material into the air, using methods common to mold remediation guidelines outlined in Institute of Inspection Cleaning and Restoration Certification (IICRC) S520 by an experienced mold remediation contractor. All exposed porous materials such as draperies, linens, mattresses, or exposed clothing were removed from the home and professionally laundered, and carpets were steam cleaned. The ductwork for the home was also cleaned by a National Air Duct

Cleaners Association (NADCA)-certified duct cleaner.

Detailed cleaning and HEPA air scrubbing of the home (approximately 4-6 air changes per hour) took place over an approximate one-week period, during which time the residents of the home temporarily relocated. Following this, the CIH requested that air scrubbers be deactivated, then the home was re-inspected approximately 16 hours later. Air levels of particulate matter initially found throughout the home (0-4000 particles per cubic foot) were dramatically lower than outdoors (8,000-15,000 particles per cubic foot), indicating that the air scrubbers were effective at removing particles from the air of the home. However, after approximately 30 minutes of walking throughout the home to conduct the inspection, air levels of dust particles in all areas began to dramatically rise to 6,000 to 11,000 particles per cubic foot, and the homeowners reported recurrence of the bitter taste in the mouth. Intentional disturbance of the carpeting in each room resulted in temporary elevations of particulate matter in the immediate vicinity of the carpeting. In addition, the dining room table and other surfaces evidenced new deposits of dust, comparable to those observed during the initial CIH inspection.

Based upon the above, it was concluded that significant reserves of dust from the insulation installation remained within the home and were being suspended and re-deposited on surfaces, presenting a continued source of unusual dust in the air throughout the living space of the home, and that carpets within the home appeared to be a continuing reservoir of these dusts. Carpets were therefore removed, repeat surface cleaning and air scrubbing of the home was performed, and HVAC ductwork was re-cleaned. This additional cleaning and air scrubbing work was completed in early to mid-September, 2009.

Following the removal of carpets and re-cleaning of the home, the home was re-inspected. Visual inspection revealed that all living space-accessible surfaces appeared to be free of any evidence of dust accumulations, consistent with evidence that cleaning efforts were conducted in accordance with customary industry standards. Despite the lack of visible dust on surfaces, air monitoring findings revealed that airborne particulate matter within the home was comparable to outdoor levels of particulate matter, suggesting a continuing source of airborne particulate matter was being released into the home. Laboratory results from the September 2009 air samples revealed that outdoor cellulose levels were approximately 130 to 170 fibers per cubic meter of air (f/m^3), comprising approximately 8% of the constituents of the particle types within the sample. Indoor air levels of cellulose were substantially higher than outdoor levels, ranging from 1,500 to 2,500 f/m^3 (comprising 35 to 39% of the sample). The laboratory analyst reiterated that the predominant form of the cellulose in the indoor samples appeared to be distinct from the outdoor cellulose type.

Based upon these findings, it was concluded that air levels of dust from the insulation were continuing to be released into the air of the living space. Because the source of the continuing cellulose dust contamination of the home could not be determined (e.g. HVAC re-entrainment, breaches in attic/living space partition, etc.), the CIH recommended that the cellulose insulation be removed from the attic in a manner that would not re-introduce cellulose or other contaminants into the living space and that the attic and return ductwork be inspected for leakage and any remnants of the blown-in insulation, as well as for any return air or other breaches which could introduce particulate or gases into the living space of the home.

In October 2009 all cellulose and original fiberglass batt insulation was removed from the attic by sealing the attic hatch doors from the living space, re-opening the gable vents, and vacuum-extracting the sprayed insulation via the gables. Following removal of the insulation, the remediation contractor placed the attic under negative pressure with respect to the remainder of the home, and HEPA vacuumed all surfaces of the attic, including roof sheathing, joists, framing, and the attic-accessible surfaces of the ceilings. This was followed by a detailed re-cleaning of the home and ductwork, then by a repeat inspection and air sampling by the CIH. Laboratory results indicated that indoor air levels of cellulose dust ranged between 67 and 200 particles per cubic meter of air, which were comparable to outdoor levels measured at 33-170 particles per cubic meter and considered normal. These post-insulation removal indoor air levels of cellulose dust were roughly 1/30th to 1/10th of levels measured previously throughout the home when the insulation was in place. No bitter taste was detected by the CIH or homeowners; symptoms of eye, respiratory, and skin irritation immediately subsided. The homeowners replaced furnishings and moved back into the home without further symptoms.

Table 1 summarizes the initial, intermediate, and final air sampling for cellulose content described above.

Table 1. Comparison of Cellulose Content in Air Samples

Location	Aug. '09	Sept. '09	Sept. '09	Oct. '09
	Cellulose %	Cellulose %	Cellulose fibers/m^3	Cellulose fibers/m^3
Outdoors	13%	8%	130-170	33-170
Indoor Living Space	26-36%	35-39%	1500-2500	67-200

DATA ANALYSIS AND IMPLICATIONS

There are several scientific and building science principles illustrated by this case that may explain some of the observations described above. Energy auditors and insulation contractors may find knowledge of these principles helpful in planning and implementing similar projects. Several of these are summarized below.

Anticipated Energy Savings from Additional Insulation

According to the Energy Star Program, attic insulation should be adequate to cover the joists and evenly distributed throughout the attic, especially toward the eaves. The energy star recommended level of attic insulation is approximately 10-14 inches, or R-38 [http://www.energystar.gov/index.cfm?c=diy.diy_attic_insulation].

Based on the above (assuming that: 1) the addition of the cellulose insulation on top of the fiberglass insulation added an additional resistance to conductive heat loss equivalent to R-10 for a total combined R-value of 40 over the approximate 1,000 square feet of ceiling area, and 2) an estimated 30°F temperature difference between the conditioned living space and attic temperature for 6 months per year) the estimated energy savings can be determined by the following:

$$Q = U \times A \times \Delta T$$

where

Q = heat flow rate in Btu/hour
U = heat conductance (1/R where R is in hr x ft^2 x°F/Btu)

A = area of heat transfer
ΔT = temperature difference

Source: *Handbook of Energy Audits*, 7th Edition 2008

Then

$$Q = (1/40 - 1/30) \times 1000 \times 30$$
$$= 1/10 \times 1000 \times 30$$
$$= 3000 \text{ Btu/hour}$$

Assuming that this temperature difference exists for 24 hours per day for 6 months per year, the annual energy savings associated with the additional attic insulation would be approximately 12,960,000 Btu/year. If roughly 50% of the savings were via reduced heating costs by a 70% efficient natural gas burning heater, and the other 50% by reduced air conditioning, this additional insulation would save the homeowner approximately 93 therms of natural gas—at $1.32/therm, an annual heating savings of $123.00—and roughly $300.00/year in air conditioning savings, depending on the specifics of the home's air-conditioner SEER rating, thermostat settings, and other factors. The combined annual savings of roughly $423.00 should be weighed against the costs of the insulation and installation.

Potential Health and Safety Risks for Insulation Product

Cellulose from recycled newsprint is not regulated as a hazardous material by the Occupational Safety and Health Administration (OSHA), nor does the American Conference of Governmental Industrial Hygienists (ACGIH) recommend any threshold limit value (TLV) specifically for airborne cellulose exposure to workers. Cellulose dust is only considered a nuisance dust, and the OSHA permissible exposure limit (PEL) for nuisance dust is 15 milligrams per cubic meter of air (mg/m^3), which, for perspective, is probably the amount of dust that you would see behind a dump truck driving down a dirt road—very high. As a general approximation, 1 mg/m^3 is approximately 6 million particles per cubic foot of air [Plog, 1996]. Based on the above, the average of 15,000 to 20,000 particles per cubic foot of air measured within the home would be far below applicable OSHA workplace exposure standards for nuisance dust and would be considered to be quite low by workplace exposure standards.

However, workplace exposure standards are not applicable to residential exposures, and the general public (which includes children, the elderly, and persons who are typically not as healthy or hearty as workers) would be exposed not for merely 8 hours per day but as much as 16-24 hours per day. Physicians and toxicologists have determined that particles with aerodynamic size of less than 10 microns are considered to be respirable, meaning that the particles are small enough to by-pass the upper regions of the respiratory tract and make it to the deep regions of the lungs, including the bronchioles and alveoli [Casarett and Doull's, 1987].

To address this concern the U.S. Environmental Protection Agency (EPA) has promulgated a National Ambient Air Quality Standard for particles of 10 microns in diameter or less of 150 micrograms per cubic meter ($\mu g/m^3$) over a 24 hour period, which is approximately 1/100th of the OSHA workplace standard. The NAAQS for particles smaller than 2.5μ is even lower, at 15 $\mu g/m^3$ annual average and 35 $\mu g/m^3$ for any 24-hour period [USEPA, NAAQS]. From this, one can see that the levels of nuisance dust measured within this home, while far below the OSHA workplace limit, may approach the range of the EPA's PM_{10} standard.

That the nuisance cellulose dust was also combined with up to 15% boric acid, ammonium sulfate, and other compounds must also be considered. Boric acid, long used as both a fire and rodent retardant, is not associated with high toxicity; however, based upon its pH of approximately 5.1 for a 0.1 molar solution (Merck Manual 9th Edition, 1976), it could be expected to cause irritation of mucous membranes such as the eyes, nose, and throat if present on the surface of airborne dusts. (The acid dissolves in the water lining of the local tissue if high levels of dust containing this material remain in the air.) Similarly, ammonium sulfate (pH=5.5) is also acidic and dissolves readily in water. (An amount of 41 grams of $(NH_4)_2SO_4$ dissolves in 100 grams of water.) Thus, it would be expected to carry the potential for upper respiratory tract irritation to susceptible exposed persons [Ammonium Sulfate MSDS http://www.jtbaker.com/msds/englishhtml/a6192.htm].

The degree to which homeowners or family members might react to elevated levels of cellulose dusts coated with up to 15% by weight of these acids and other compounds cannot be generalized based upon this information alone; however, this analysis suggests that adequate cause exists for care in preventing dust releases during application. Based upon all of the above, it is suggested that contractors take care to prevent high levels of airborne dusts from being released into the general air of homes when installing blown cellulose insulation, despite its general low toxicity. Furthermore, the importance of dust control may be heightened in residential homes as compared to commercial or other workplaces, given the low fresh air dilution rate of residential structures. According to American Society of Heating Refrigeration and Air-Conditioning Engineers (ASHRAE) standard 62.2, fresh air infiltration rates for existing residential structures can be estimated by:

$$Q=0.01 \times A + 7.5 \times (N_{br} + 1)$$

where

A = square feet of occupied space
N_{br} = number of bedrooms

Based upon the above, the nominal ventilation rate for a 4-bedroom, 2500-square-foot home is approximately 62.5 cubic feet per minute (cfm), or 3750 cubic feet per hour (approximately 0.1875 air changes per hour). Using Table 4.1a of the standard, the minimum fresh air introduction rate is approximately 90 cfm [ASHRAE 62.2-2007]. This is approximately ½ of the dilution ventilate rate that a comparably-sized commercial space would receive, assuming 0.06 cfm/square foot, or 150 cfm for a 2,500-square-foot area, based on ASHRAE 62.1-2007. If compared to ASHRAE 62-1999, where the minimum fresh air introduction rate for offices was 20 cfm/person at an assumed occupancy density of 7 persons/1000 ft^2, the fresh air dilution rate for a 2500 ft^2 area would be approximately 350 cfm, or roughly 3.8 times the ventilation rate for a comparably sized home. These lower residential dilution ventilation rates mean that any airborne dusts released into the home will remain trapped within the home for very long periods of time, in comparison to commercial spaces. Contractors should appreciate that air contaminants released into homes remain for extended time periods in comparison to commercial or manufacturing environments.

A related factor to consider is that the sealing of the attic soffits or other air breaches to the exterior of the home may have not only made the blowback of insulation dust into the home more likely but also carries with it the risk that any off-gassing of ammonia or other gases from the insulation product within the attic (where temperatures easily reach over 100°F during the summer months) would lead to an accumulation

of these gases therein. As temperatures rise within the attic, so too does vapor pressure of any gases or vapors. If pressure can not be relieved to the outside, the only route for escape of the accumulation of gases or vapors is to the living space via ventilation ductwork, recessed lighting, bathroom vent stack cut outs, or utility breaches.

Particle Settling Velocity Estimates

This investigation revealed that over the course of the project, despite numerous cleaning efforts, including HEPA vacuuming and HEPA air scrubbing, settled dusts continued to be observed on horizontal surfaces of the home. These dusts were typically observed 12-16 hours following cleaning and deactivation of the air scrubbers. We also observed that air levels of dusts were quite low in the attic space but rose dramatically within ½ hour after entry into the home. Airborne dust levels that were initially quite low had more than doubled when horizontal surfaces, including carpets, had been disturbed.

This observation can be explained based on particle-settling velocities. Stokes law describes the terminal settling velocity of spherical objects in a fluid such as air, based upon factors which include the effect of gravity, aerodynamic diameter, and particle density [Plog, 1996]. While aerodynamic diameter can be complex to compute, approximations of settling velocities for the cellulose fibers released into the air of the home can be estimated. Assuming an aerodynamic diameter of approximately 4 microns and an average density of 2 (compared to air), estimated settling velocity for the cellulose fibers can be estimated, using:

$$V_s=0.006 \times sg \times d^2$$

where

Vs = settling velocity in feet per minute
sg = particle density
d = aerodynamic diameter

therefore

$Vs = 0.006 \times 2 \times 4^2$
$Vs = 0.19$ feet per minute

Based upon the above, it can be seen that airborne cellulose particles will settle to the floor at a rate of approximately 5 minutes per foot, or stated another way, a particle suspended in air approximately 6 feet above the floor would take 30 minutes to settle to the floor. Each time that particles having settled onto the floor, carpeting, or upholstery are disturbed by walking, or sitting on a sofa, they will be re-suspended into the air where they will again take 30 minutes or so to be re-deposited. This is why we observed both the low airborne levels of suspended dusts in the attic (i.e. no air movement and no disturbance) and also why low initial air levels of airborne dusts, upon entry into the home, were followed approximately 30 minutes later by high levels of airborne dusts (after carpets were walked upon). This also explains why 12 hours following deactivation of HEPA scrubbers, high levels of surface dust were observed on wooden furniture throughout the unoccupied home. It is because of this Stokes settling velocity principle that visual inspection, air monitoring, and air sampling for dusts were always conducted not immediately following, but rather several hours following cleaning of the home, and it is why the heating and air conditioning ductwork had to be re-cleaned on multiple occasions.

CONCLUSIONS

This article described eye, respiratory, and mouth irritation following a cellulose insulation application in the attic of a home and the methods to assess and remediate the home. Contractors should carefully evaluate the configuration of the home to devise means of preventing fugitive releases of insulation dust into the living space when applying cellulose insulation. Factors such as the configuration of the attic, ventilation, pressure relief, and suppression of dusts should be considered. It is also suggested that contractors consider that, despite the low toxicity of the individual components of the cellulose insulation, very small-sized insulation dust particles released into the home may be a source of discomfort for some members of the general public who are susceptible to respiratory irritation, especially given the acidic nature of the rodent and fire suppressants which are components of the cellulose insulation dust. This may be especially important in homes where the nominal dilution ventilation rate is substantially lower than comparably-sized commercial or manufacturing spaces. Attention should be given to the possibility of chemical off-gassing of ammonia or other gases when exposed to elevated attic air temperatures, especially if attic ventilation to the exterior of the home is suppressed by weatherproofing or sealing techniques. Finally, when remediating insulation or other particulate contamination of homes, consideration of the small particle size and slow settling velocities of dust particles may help in planning remediation measures and remediation verification monitoring methods.

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