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Forensic Engineering of Indoor Air Quality

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Abstract

Forensic Engineering of Indoor Air Quality is both an art and a science. While there are several standards, guidelines, and experienced based judgments, some are contradictory. This paper discusses a risk assessment approach that considers hazard evaluation, dose-response assessment, exposure assessment, and risk characterization. Hazard evaluation, in some cases, depends upon evaluation according to physical or chemical characteristics. For example, mold spores are considered fine particulate matter for evaluation against the National Ambient Air Quality Standard for Particulate Matter. Simple exposure to a contaminant is not sufficient to provoke a response; demonstrating a reasonable expectation of a linked response is necessary. Time and route of exposure are other factors that must be demonstrated. These factors are combined in a risk assessment to describe the probability of a link between cause and effect. Three cases are presented where these elements were established sufficiently to persuade judicial decisions.

Complex Issue

Indoor air quality is a rapidly growing field with few barriers to entry for those who offer services. Homeowners, industrial plant managers, commercial building owners, and others who may need help rarely understand the skills necessary to identify and correct indoor air problems. The marketplace abounds with numerous "certifications", like the Certified Mold Remediator (CMR) that can be obtained by paying the appropriate fee, attending a 2 ½ day training session, and passing a short exam that apparently no one has ever failed. College studies are not required for these "certifications". By comparison, the Certified Industrial Hygienist (CIH) has comprehensive training and experience evident in a baccalaureate degree in science or engineering and four years of qualifying experience – prior to passing 8 hours of examination, which has a pass rate of less than 50%. The CIH certification is accredited by an independent agency, the Council of Engineering and Scientific Boards (CESB). Most consumers of indoor air quality services cannot distinguish between a CIH and CMR on a business card and may think both equally qualified. The CIH is highly skilled but can be too narrowly focused to understand the full breadth of some indoor air quality problems.

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Licensed Professional Engineers (PE) make practical use of the knowledge of pure sciences (physics, chemistry, and biology) in the design, construction, and operation of buildings, systems, and processes. PE's hold accredited baccalaureate degrees in engineering, have four years qualifying experience and pass both an eight hour Fundamentals of Engineering exam and the eight hour Principles and Practices exam. States restrict the practice of engineering professionals to their area of expertise. The American Academy of Environmental Engineers offers a CESB Board Certified Environmental Engineer (BCEE) to PE's with four years additional experience that pass an oral and written examination. Engineers are highly qualified and can help identify sources of water or moisture intrusion, problems with mechanical systems, and their impact on the broader environment.

A Professional Engineer can further validate experience as a Board Certified Diplomat in Forensic Engineering with the National Academy of Forensic Engineers, which is formally affiliated with the National Society of Professional Engineers (NSPE). To qualify for this exclusive, Engineering Board Specialty Certification (there are approximately 500 Diplomat members nationally), a candidate must have an appropriate engineering education and practical experience, including actual experience in forensic engineering. In addition, the candidate must provide acceptable, detailed references from attorneys, senior claims managers or NAFE members who are personally familiar with his or her forensic practice and experience. Typically a Professional Engineer that can meet the standards for this demanding Engineering Specialty Board review is a senior level engineer with several decades of experience as a working consulting engineer with actual trial experience. The use of an Engineering Board Certified Forensic Engineer, who also has a solid technical background in Indoor Air Quality (IAQ), is essential to be able to realistically evaluate and solve IAQ problems.

Poor air quality can be complex and require a range of skill to identify and correct. The forensic engineer must identify the problem accurately and precisely in order to facilitate a fair and equitable resolution of judicial matters. When the air is adversely affected by water intrusion, identifying the origin and cause often requires the skill of an engineer. Occasionally, the air inside encapsulates unhealthy air from outside. For example, Atlanta is classified as serious non-attainment for ozone. Symptoms associated with exposure include cough, chest pain, and throat irritation. Ozone can also increase susceptibility to respiratory infections. In addition, ozone impairs normal functioning of the lungs and reduces the ability to perform physical exercise. These are symptoms which have also been attributed to mold exposure.

There are various standards, guidelines, opinions, and just plain nonsense that have been applied to indoor air quality. Federal regulatory standards with health based effect concentrations include the Occupational Safety and Health Administration (OSHA) Permissible Exposure Level (PEL) for numerous pollutants. These are workplace standards which recognize that the PEL over a 40-hour workweek will not cause adverse health effects to most workers. While this may be appropriate for the factory floor, it is not the standard for homes, and perhaps not even offices. The Environmental Protection Agency (EPA) National Ambient Air Quality Standard (NAAQS) is the health based federal regulatory standard that applies outside the factory property line, and in homes. The American Conference of Governmental Industrial Hygienist (ACGIH) is a scientific association that has established committees that review existing published, peer-reviewed scientific literature. ACGIH publishes guidelines known as Threshold Limit Values (TLV) for use by industrial hygienists in making decisions regarding safe levels of exposure in the work place. The National Institute of Occupational Safety and Health (NIOSH) develop criteria documents and Current Intelligence Bulletins with Recommended Exposure Levels (REL) for the workplace that sometimes undergo subsequent regulatory review as OSHA rules on a PEL. These standards and guidelines have limited applicability, and must be used with some expertise and judgment. In cases where they do not apply, common sense often forms the basis for opinion. Are measured concentrations higher inside than outside? If so, answering the obvious “So what?” requires considerable engineering judgment.

Indoor air quality issues are often highly charged and emotional. A homeowner may feel their health at risk and their greatest financial investment in jeopardy. An office worker may feel economically trapped in a setting that is unhealthy. A factory worker may think the employer expects him to endure a dangerous environment as a normal consequence of employment. Fear about health and wealth, combined with lack of control often make this a highly charged situation.

The Analytical Construct

The problem can be approached by addressing three simple questions: “What’s so?”, “So what?” and, “What now?” The first of these is the basic information gathering phase. The second puts the information into context. And the final question offers a recommendation for resolution, or course of action. Forensic engineers can be helpful with the first two, and often offer recommendations. However, the final resolution is often left to the judicial system.

“What’s so?” is often developed in a phased approach where subsequent inquiry leads to increasingly detailed information about the indoor environment and occupants. Phase I may be information presented with the initial case assignment; often third hand information from the case manager and reports from previous studies or evaluations. Phase I usually offers a basis for additional inquiry for a Phase II where some information gaps can be filled. Phase II may include sampling, review of medical records, and collecting additional data from other sources such as water company invoices, NAAQS data, or medical record detail. This level of inquiry may not fully resolve information needs and further investigation may be necessary.

Information will never be complete and engineering judgment will necessarily be based on limited data. Sometimes witnesses are not available to provide first hand accounts. Access may be restricted for a variety of reasons including subsequent transfer of ownership, demolition, or major remodeling that makes the indoor space different from conditions in question. Sampling after the exposure event may not be representative. Sometimes there is contradictory information; forensic engineers are typically involved in matters under dispute.

In order to be useful to the judicial system, “What’s So?” must be distilled into “So What?” A lot of information is gathered in the “What’s So?” phase. The forensic engineer must present the relevant date in a context that can serve as the basis for decision-making. A risk assessment approach offers a construct that has been used successfully in a number of cases. This is a four-step process which begins with hazard evaluation, progresses to dose-response assessment, then to exposure assessment, ultimately leading to a risk characterization.

A hazard evaluation addresses whether or not the substance, process, action, or event has the potential to pose a risk. In the case of a chemical, toxicity data is reviewed. Physical and chemical properties of substances are considered. Information that a material will spontaneously ignite or that it will react violently in the presence of other substances may be important. Lack of information is not proof that a material is safe. However, if a substance has been studied extensively and hazards are not demonstrated the argument can be made that at least by comparison with another where hazards are proved, the substance is safer.

Materials that have well documented hazards often have substantial information about how much exposure to a chemical is needed to elicit a specific adverse effect. ACGIH publishes documentation for each TLV, which serves as the basis for establishing safe levels of exposure. These are literature reviews and summaries of peer-reviewed literature that are used to establish the dose-response assessment. US EPA publishes Criteria Documents for each of the NAAQS that, in considerably more detail than ACGIH, discusses the basis for each standard. There is similar documentation in the public record for the dose-response relationship basis of RELs and PELs. These cover only a few of the chemicals that people are exposed to in the environment and in the workplace. The forensic engineer will have to develop and present information regarding dose-response for other chemicals. Because of the abundance of junk science available, considerable scientific rigor will be required to present credible information.

The next step is an exposure assessment. Once it is established that a hazard is present and that there is a dose-response relationship, it is necessary to determine if the individual was exposed to a sufficient dose to elicit a specific adverse effect. Dose means not only the concentration of a contaminant, but also the time of exposure. For example, a 15-minute exposure to 3 parts per million (ppm) of sulfur dioxide in an eight hour monitoring event where this is the only excursion above 1.5 ppm does not meet this time of exposure criterion. This is supported by ACGIH Short Term Exposure Limit of 5 ppm for sulfur dioxide that argues a 15-minute exposure to that level is safe for almost all workers. Multiple routes of exposure must be considered also; some chemicals can be absorbed through the skin, inhaled and ingested simultaneously. Also, there are methodologies to evaluate the combined exposure of similar chemicals when their effect is additive.

The final step is to present a risk characterization based on the previous hazard evaluation, does-response assessment, and exposure assessment. As a nation, we seem to accept a 1:1,000,000 risk of cancer from exposure in the environment. At least that is what US EPA uses as a starting point in establishing limits. EPA has accepted higher risks (e.g., 1:10,000 for benzene in groundwater and 1:1,000 for radon in basements). Courts will decide the appropriate risk for a particular case based on the information presented. There are numerous ways to characterize risk in the literature. For non-carcinogenic substances, one of the easiest to explain is the Hazard Quotient or Hazard Index. This compares the chronic daily intake to the reference dose that causes harm – when this is greater than one there is a problem.

All four steps are needed to show a link between indoor air quality and harm to an individual. Simply put, when there is no hazard, there is no harm. When there is no dose-response relationship, there is no harm. When there is no exposure, there is no harm. And where there is no risk, there is no harm. This will be illustrated in three case studies that follow. This approach has been used in cases involving a wide range of chemical exposures in the home, workplace, and office setting. In order to simplify the discussion, cases involving a common agent of harm (mold) are used. This approach will simplify the model by illustrating it across several cases without changing the technology.

The first case involves a university office in metro-Atlanta where the model is applied for the defense. The second and third cases support the plaintiff and are set in a travel agency office in rural Connecticut and an apartment complex in Savannah, Georgia.

University Office (Defense)

There were several building envelope issues that may have caused water intrusion into this building. The most entertaining was speculation that there were bullet holes in the roof resulting from New Year's Eve revelers in downtown Atlanta. The most likely cause was failure of an interior roof drain that released an unknown volume of water behind walls for an undetermined time.

When the water release was discovered, a mold remediation contractor (MRC) was called in to begin repairs. The MRC sealed off affected rooms with total enclosures and negative air pressure, removed water damaged wall-board, and cleaned mold on surfaces where it appeared. Some tape samples were collected and analyzed indicating the presence of mold.

A twenty-eight year old African-American female employee was clinically diagnosed with sarcoidosis. A worker's compensation claim was made that this disease was caused by exposure to mold in the workplace. In Georgia (O.C.G.A § 34-9-280(2)), to be compensable as an occupational disease all five of the following criteria must be met:

1. A direct causal connection between the condition under which the work is performed and the disease;
2. That the disease followed as a natural course of exposure by reason of the employment;
3. That the disease is not of a character to which the employee may have had substantial exposure outside of the employment;
4. That the disease is not an ordinary disease of life to which the general public is exposed;
5. That the disease must appear to have had its origin in a risk connected with the employment and to have flowed form that source as a natural consequence.

In order to better describe "What's So?" additional sampling was indicated. If the employee was exposed to mold in the workplace, she probably did not ingest it from surfaces where tape samples were collected, and if so, it did not result as a natural consequence of her work. The forensic engineer collected air samples to characterize potential occupant exposure to airborne viable mold and bacteria. Air was drawn through an Anderson sample at a calibrated flow rate for a pre-determined time. The Anderson sampler impinged particles in the air stream on seven agar places with various growth media. Seven samples were collected at each site and sample plates were incubated for two weeks at controlled temperatures to selectively grow mold, and environmental, human commensal and thermophilic bacteria. Basic indoor air quality parameters of temperature, relative humidity, carbon dioxide and carbon monoxide were also sampled.

Sampling indicated that the airborne concentration of mold and bacteria outside was greater than inside. Carbon monoxide measurements were higher (2 – 4 PPM) than outside (1 PPM) in one office. Other indoor air quality measurements were unremarkable.

The elevated carbon monoxide measurements were attributed to a source in the next room; a garage where a powered industrial truck had recently parked for the evening.

“So What?” was answered within the framework of risk assessment. Hazard evaluation considered exposure to carbon monoxide and to mold and bacteria. There is documentation that these can be hazardous.

There is a dose-response threshold for workplace exposure to carbon monoxide in regulation (PEL) and scientific literature (TWA). Generalized information is presented in the cases that follow regarding a dose-response relationship for mold and bacteria. Some scientists think that sarcoidosis develops when the immune system responds to something in the environment (e.g., bacteria, viruses, dust, chemicals) or perhaps to body tissue (autoimmunity). Specific triggers have not been identified; however the disease only develops when certain genes are present. Sarcoidosis occurs most often in adult African-Americans (especially women) between the ages of twenty and forty. Brothers, sisters, parents, and children of people who have sarciodosis are more likely than others to have the disease. A review of medical history revealed that the claimant’s mother has sarcoidosis.

Air quality data indicated that exposure to mold and bacteria outside was greater than inside. Therefore, if her disease was triggered by exposure to these bioaerosols, it was more likely triggered on the way to, or after leaving, the workplace. Possible exposure to carbon monoxide was well below the dose-response level of concern.

This case was concluded favorably for the Defense.

Travel Agency Office (Plaintiff)

Prior to its current use as a travel agency office, this old building had served as a service station and a retail outlet. There was a well-documented history of water intrusion over an extended period of time. MRC and others had sampled and performed remediation several times. A physician diagnosed an office worker with asthma and decreased lung function secondary to asthma that began with workplace exposure.

Using the same hazard evolution approach to answer "So What?" begins with a hazard assessment. The scientific literature is abundant with information that airborne exposure to mold can be problematic. However, distinguishing mold exposure from other substances in the air, which may create a hazard is difficult. It is clear that moisture can promote a variety of airborne substances that can collectively be characterized as particulate matter. Mold spores are generally in a size range that is deeply respirable (d < 2.5 microns).

There is a dose-response relationship for fine particulate matter ($PM_{2.5}$) established in federal regulation as the National Ambient Air Quality Standard (NAAQS). This parameter was not measured in the office. However, the physician's diagnosis includes his medical opinion that the claimant was exposed to a symptom-causing dose in the workplace.

Based on presentation of the risk characterization model, with hazard assessment, dose-response assessment, exposure assessment, and risk characterization, this case was decided favorably for the Plaintiff.

Apartment Complex (Plaintiff)

This third case involves a low-income housing complex that was owned by one company and managed by another. The Management Company routinely performed and reported on Zone Inspections. There were numerous reports of damaged wood on buildings due to water intrusion. Often these were classified as persistent (defined as meaning, no funds from the owner to repair but they are aware of the problem) and a liability. A review of damage reports indicated recurring plumbing failures that resulted in water intrusion.

There was no mold survey or data available. However, there was testimony of observed mold, and clearly conditions were right for bioamplification. Specifically, there was abundant moisture, nutrients, time and temperature to promote mold growth. There was also a physician diagnosis of decreased lung function associated with moldy conditions.

The hazard assessment was based on mold as fine particulate matter. The dose-response relationship was based on the NAAQS for $PM_{2.5}$. The exposure assessment was based on the physician diagnosis. The risk characterization concluded that as a result of multiple sources of water intrusion over an extended period of time, a symptom-causing dose was absorbed causing adverse health effects.

This case was resolved favorably for the Plaintiff.

Conclusion

The three examples presented involved mold to introduce a risk assessment approach applicable to cases involving any environmental contaminant where there is a claim of harm to people. This four-step process requires affirmative information for each inquiry in order to establish a cause-effect relationship. In bullitized format, where there is;

- No hazard – no harm
- No dose-response relationship – no harm
- No exposure – no harm
- No risk – no harm

Risk assessment addresses the "So What?" in the trilogy on indoor air quality queries;

- What's So?
- So What?
- What Now?

This simplified approach offers a model to organize and present information on indoor air quality cases for judicial review.