

Indoor Air Quality Management and Infection Control in Health Care Facility Construction

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IAQ T3S1 Innovative techniques in IAQ

ABSTRACT

The assessment of indoor air quality (IAQ) risks to building occupants has become a complex and challenging issue for building owners and facility managers. Recent research has defined causal links between construction practices and infection rates in health care building and renovation projects. Attention to IAQ management during building construction is being elevated because of its potential role in fungal, mold, related problems in buildings.

Advanced environmental control techniques and are now being developed to better manage IAQ in health care facilities, including improved particulate control, air disinfection systems, moisture control, and pressurization strategies. Each of these creates additional sequencing and process requirements during construction with related implications for construction cost and schedules. As a result, the role of the contractor in managing and implementing indoor air quality in health care construction and renovation is becoming increasingly complex.

This paper presents an analysis the relationships emerging between IAQ technologies and construction practices, with an emphasis on health care facility construction. A case study of IAQ management during construction is presented to illustrate the lack of current formal processes, and the implications of state-of-the art infection control strategies on construction projects. Recommendations are made for improved assessment, control, and monitoring of moisture in buildings during construction as an example of how to improve current practice. Future directions for research in this critical area of the construction industry are also provided.

Key Words: Indoor Air Quality, Healthcare Construction, Mold, Allergen, IAQ Risk

1. INTRODUCTION: SOURCES OF IAQ RISK IN HEALTHCARE CONSTRUCTION

The US Environmental Protection Agency (EPA) recently called Indoor Air Quality (IAQ) one of the most important environmental health problems in the 1990s. IAQ problems generally are caused by two circumstances: (1) poor or inadequate ventilation and (2) exposure to one or more contaminant sources in the building (MS Hospital Consulting, 2001).

The Centers for Disease Control and Prevention estimates that more than 2 million patients a year acquire infections in U.S. hospitals while they are hospitalized for other health problems, and that 88,000 die as a direct or indirect result. It is estimated that about 5,000 of these are related to

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construction and maintenance practices. The numbers indicate that hospitals are not always doing enough to keep seriously ill patients a safe distance from construction projects, partly because, until recently, hospitals haven't had specific, detailed information on how best to do that (Burmhal, 2003).

Roughly \$10 Billion a year is spent on healthcare facility construction in the US every year. Approximately 70% of the total amount is spent on renovation, and 30% is for new construction. More than ever, designers, architects, engineers, facility managers, and construction managers need to fully understand how renovations and construction projects can compromise the air quality of patients (Cheple, 1998).

Statistical Factors Related to Patient Risk

Healthcare facilities have to pay particular care and attention to indoor air concerns. People with pre-existing health problems who are going through treatment and those who may have depressed immune systems are very susceptible to indoor air exposures. Three key factors make attention to indoor air quality particularly important in health care settings.

1. *Patients at risk*: healthcare facilities house many persons with heightened susceptibility to infections, respiratory distress, and other problems associated with air contaminants
2. *Occupant density*: Because the density of people in health care settings is relatively high, at risk patients are likely to be in close proximity to infectious individuals.
3. *Aging systems*: Many hospitals are aging and their ventilation systems are outdated and are in serious need of maintenance and repair.

Causal Factors: Fungal and Mold Contaminants

Construction procedures that can heighten infection risk in health-care environments include demolition using inadequate barriers, exterior-wall removal, and core drilling. The main cause of construction-related infection is airborne fungal spores, which originate on water-damaged building materials. A mold like *Aspergillus* can grow on modern building materials such as gypsum board and ceiling tile if they are allowed to stay wet more than 72 hours. (MS Hospital Consulting, 2001). The spores become airborne during repair/disturbance. They have low settling velocities, remaining in the air for long periods of time (Streifel and Hendrickson, 2002).

Water leakage, poor ventilation, and utility outages also increase the probability of initiating fungal growths in the building system. Biological contaminants such as bacteria, mold, and viruses can breed in water that has gradually accumulated in ducts, humidifiers and drain pans of the ventilation system; or water that has collected on ceiling tiles, carpeting, or insulation. This is particularly a problem in older buildings that may have broken fans or other maintenance problems. Such maintenance problems may be common since many healthcare facilities are always looking for ways to save money (Quayle C. 1997).

The National Institute of Occupational Safety and Health reports a high level of both molds and bacteria, especially bacillus species in air samples taken from health care facilities. Contaminated fibrous insulation samples taken from air ducts where allergic complaints have been identified have also been documented (MS Hospital Consulting, 2001).

Airborne fungi are common and for most individuals breathing typical ambient concentrations of airborne fungi results in no adverse effects on health. Very little data directly relates indoor airborne contaminants to human health effects because the concentrations of the contaminants are very low and health effects are usually the result of combination of indoor and outdoor exposures over a long time period. However, hospitalized patients with immune suppression are susceptible to infections from naturally occurring airborne fungi that can grow at body

temperatures. The incidence of infections caused by fungi that were once considered only saprophytic has risen dramatically in recent years, for example, hospital mortality caused by invasive aspergillosis (Kuehn, T. H., 1996). Aspergillosis is acquired by inhalation of airborne dust particles that carry the spores. Pneumonia develops and the fungus disseminates through the blood stream to other organs. Mortality rates have been reported as high as:

- 95% in bone marrow transplant patients;
- 13-80% in leukemia patients; and
- 8-30% in kidney transplant patients.

Although considerable effort is taken to protect patients against infection, construction related activity within the building can generate additional fungal spores. Improper control of the indoor air cleanliness during construction can result in increased patient exposure, illness and death. Several reports document the link between construction activity and patient infection. No microbial sampling was conducted during patient exposure in most cases. However, there is sufficient evidence to suggest that construction related activity is the main cause.

2.0 PRACTICES TO MINIMIZE RISK

HVAC System Design and Operation

Because patients have infections that can spread through the air, control of air movement and air cleaning are critically important. In the case of airborne infectious diseases like TB, patients are often kept in special infectious isolation rooms that are under negative pressure so that contaminated air will not leak out of the room. However, often people who may be infectious may not be diagnosed right away so those in emergency rooms (ER) are most at risk.

To minimize this risk, some hospitals are taking steps to design their facilities to limit the spread of infectious diseases. For example, when the Children's Hospital in Fort Worth, Texas renovated their emergency room in 1996, they had the rooms designed to decrease the chance of airborne transmission of diseases. The waiting room HVAC system was designed to push air through the room from inlet to outlet with as little mixing as possible (displacement ventilation). By limiting mixing, a displacement ventilation system prevents the wide distribution of airborne pathogens within the space so that only persons in proximity to an infected individual are likely to be exposed. Once the air passes through the waiting room to the return air duct, it passes through a HEPA filter. A HEPA filter must capture 99.99% of particles of 0.3 μm (micrometers) in diameter and is even more efficient in other size ranges. Most bacteria are 0.5 to 10 μm and tuberculosis is 1 to 5 so these filters should capture any infectious organisms in the air. By using the HEPA filter in the return duct, the return air is cleaned sufficiently to permit a portion of it to be recirculated rather than exhausted. Consequently, the hospital saves the cost of the energy that would be consumed by conditioning the make-up air in a 100% outside air system.

All parts of the humidification and dehumidification systems must be kept clean and dry to prevent growth of bacteria and fungi. Otherwise, microorganisms can become airborne and infect patients who have suppressed immune systems. Moisture in other areas may also contribute to the growth of mold from increased humidity. For example, certain respiratory care equipment produces a lot of mist, which can increase the humidity levels in a room. These rooms need to be cleaned particularly well to prevent the growth of mold.

Patient Bed Management

If there are patients who come in who have signs or symptoms of an infectious disease, they are put in a separate room that does have 100% exhausts to the outside so there is no chance of the air returning to the hospital. These rooms can also be put under negative pressure so infected air from inside of them won't get out into spaces like hallways (Martone WJ, Jarvis WR, 1992).

For high-risk patients, like those whose immune systems are compromised, there may be special rooms that are under positive pressure in which fresh air flows into the room and there is positive pressure built up so that no contaminants can come in from the outside. These rooms are called protective isolation rooms since they are designed to protect the patient. One important contaminant in the air that these at risk patients are being protected from is fungi.

Green Hospitals and LEED™

The Leadership in Energy and Environmental Design (LEED™) green building rating system, a product of the U.S. Green Buildings Council that was launched about 1998 has significantly elevated awareness of both energy efficiency and indoor air quality. The system identifies six primary areas: sustainable sites; water efficiency; energy and atmosphere; materials and resources; indoor environmental quality; and innovation and design. A design process aimed at satisfying LEED™ certification almost invariably results in buildings with lower operational costs and significantly improved environment and air quality.

Of a total of about 450 buildings nationwide that have registered for certification under LEED™, including several healthcare facilities. One facility has entered the American Society for Healthcare Engineering's (ASHE) sustainable building award program (Al Sunseri, 2003). It is expected that this number will grow significantly in the next decade, and that a version of the LEED™ system will be developed specifically for healthcare construction and renovation.

While LEED™ has been successful in the marketplace with commercial, public sector and even private corporate buildings working through the LEED™ document, it currently contains no specific information to meet health care facilities' special needs, such as round the clock operation, infection control, air changes and building code regulations.

3. Construction Practices for Fungal Risk Mitigation

To be effective, the control of indoor airborne microorganism concentrations during construction requires cooperative effort between the architectural and engineering design team and implementation by healthcare facility staff and the contractors. Thorough infection prevention and control measures must be employed throughout construction and renovation projects in health care facilities to reduce health risks. All parties involved in the construction process must take into account precautions for infection control risk management planning for construction projects. As an integral part of prevention, clear lines of communication among all personnel involved must be established in the planning phase of the project, and guidelines should be developed and followed to ensure that an effective communication plan is used throughout the project (Boyd N, Mindorff C, Bruce D et al., 1993)

Communications, coordination, planning: those qualities are important throughout the renovation of a health care campus if the institution is to maintain its image as a safe, sterile, highly efficient and healing environment for patients while contending with temporary facilities, excavations, construction equipment and an army of contractors.

Risk Assessment

Recognizing the potential impact of the release and movement of bacteria during construction, as well as the ongoing issue of infections, infection control risk assessment and management are an integral part of the planning process. A strong existing body of research exists on the assessment of IAQ risk during healthcare construction. This research emphasizes the classification of risk based on the types of healthcare facilities and the potential contaminant exposure of patients with variable levels of vulnerability to infection. A series of increasingly elaborate precautions are then recommended in areas of increasing risk, including dust and moisture control practices, pressurization strategies, and the construction of temporary barriers between construction areas and occupied spaces.

Constructability and Work Sequencing

Key project elements that create challenges on a health care industry are related to constructability. The constraints affect not only the design of a renovation, addition or new facility, but also the construction staging, especially the placement and operation of cranes.

Work sequencing plays a critical role in solving many of these dilemmas. It might even make sense to redesign an addition or renovation to reduce disruptions to ongoing activities. In one case, a small addition was built on one end of an existing building to accommodate those using the structure while the other end of the building was being remodeled. This resulted in a significant savings over the cost of renting temporary space while providing additional permanent "swing" space to meet future needs.

Minimizing inconvenience to patients during construction is one of the key goals of every owner. The owner, construction manager, architect and program manager must work together to develop a design that can be constructed quickly and efficiently. In one case, a projected five-year construction schedule was halved to avoid inconvenience to patients and potential loss of revenue.

Effective construction sequencing and placement of air handling units are key to effective infection control, both during construction and over the long term. In addition, the sealing of ductwork and diffuser during construction are vital to the minimization of dust and moisture in HVAC distribution systems that can lead to IAQ problems later on. The control of humidity during construction often requires that mechanical systems must be used during construction, further complicating efforts to keep these systems clean, and in some cases, requiring the acceleration of the construction of these systems. In some cases, contractors are turning to temporary HVAC systems for use during construction to minimize the impact of dust and moisture risk to the permanent systems. This practice adds significantly to general conditions costs.

Central receiving, storage and trash removal, both temporary and permanent, are other issues that become more complex in a hospital setting. The design and construction team must consider such issues as whether an addition requires a new loading dock or can share an existing central loading dock; the route that must be traveled to remove trash and medical waste; and the potential impact on future expansion.

Current Practice Case Study

In a recent case study of a major federal healthcare facility construction project, several significant issues were noted indicating that additional research is needed to help improve the management of IAQ risk during construction. The following points summarize the findings of this study:

A high number of moisture sources were found on the project that could lead to IAQ problems, including roof penetrations and tests of plumbing and mechanical systems. One of the biggest problem areas was the building envelope which included several types of façade systems such as masonry, glazing, metal panels, and precast elements. This complex façade required several contractors to complete, and introduced a complex set of joints and flashing details. In some cases there were disputes about who “owned” different joints that delayed construction. Some of the caulking and flashing joints were completely omitted from design drawings, causing further delays to the completion of the envelope, and subsequent leaks and moisture intrusion during construction.

The use of the permanent air conditioning system was planned to manage humidity levels during construction. Problems were encountered with the control of this system, as not all of the control instrumentation was completed at the time of temporary start-up. Also, the insulation of the ductwork was problematic. The duct insulation contractor followed a common practice in which some sections of insulation were left out (elbows) as crews installed the easy (straight) runs of insulation first. As a result, sections that were missing insulation created condensation problems when the system was started.

A mold abatement contractor was employed on the project by the general contractor to abate mold in the event it was detected during construction. The detection of mold problems however, was limited to visual inspection. While extra efforts were made to inspect areas that moisture intrusion was detected, overall the detection of mold during construction was not systematic. Also, significant problems were encountered with the procurement of insurance for the abatement contractor.

This case illustrates examples of design, construction sequencing, and risk abatement issues that can arise during healthcare construction. In addition, the lack of formal planning and management of IAQ risks on this project indicates the need for standard practices to be developed and implemented throughout the industry.

RESEARCH PROGRAM OVERVIEW

A new research program on IAQ issues in Healthcare construction has been initiated at the Center for Indoor Environment Quality (IEQ) housed in the Department of Architectural Engineering at Penn State. This program is collaboration between faculty in mechanical systems design, construction engineering, and the Hershey Medical Center (Penn State’s School of Medicine). This program is currently focused on defining the relationships between IAQ risks and construction practices, and developing strategies for owner and contractors to manage this risk during construction. As awareness of IAQ risks permeates throughout the industry, it is expected that the lessons learned through this research will be applied to other sectors of the building industry. The balance of this paper summarizes the initial focus of this collaborative effort.

Defining the Sources and Contaminant Pathways Caused by Construction

Many construction activities generate and disperse contaminants that compromise the quality of the indoor environment. Contaminant penetration from outside sources is dependent on building openings such a windows, doors, cracks, or air intakes. Other factors include the amount of outdoor ventilation air that enters the building and the level of cleaning applied. Indoor construction sites are an obvious source of indoor pollution because of the potential for creating obnoxious and hazardous airborne material. The effects of external and internal construction activities have not been addressed with hospitalized immune-compromised patients.

Sources of outside air pollution from construction projects range from asphalt roofing exhaust to particles generated by excavation process. Outdoor sources are various and often difficult to

correlate with a particular activity. Vivid increases of indoor aerosols might be noticed during and after demolition of close by buildings. The production of a microbial aerosol from an outside project takes place mostly during excavation when large amounts of dirt movement disrupt the natural environment of the fungi. The airborne spores can enter buildings through penetrations and, if the building is a hospital, may reach a susceptible patient if building air intakes do not have final high-efficiency filters. Several institutions have experienced patient-related problems associated with the improper installation of filtration and nearby excavation. Preventing such source penetration from the outside seems more readily attain- able than recognition and containment of contaminants generated indoors.

A Model for IAQ Management in HealthCare Construction and Renovation

There is a visible absence of standard practices and advice for general contractors that provide both practical advice and a standard of care for managing IAQ risks in healthcare renovation and construction. One effort in progress is the development of a comprehensive guide for contractors to use to prepare for and managed IAQ issues during construction. A brief overview of this model is presented in Table 1.

Table.1: A Process Model for IAQ Management in Construction

Processes	Description of Processes
1. Identify Project & Determine Risk	Guidelines are provided for the assessment of IAQ risks based on both infection control risks and project features (such as complex envelope construction) that will require steps to mitigate and manage.
2. Pre-Construction Planning	A guide for the contractor’s involvement with hospital facility management staff during the beginning phases of construction planning is provided to help identify needed support configurations and phasing required to prevent and control airborne contamination.
3. Estimating and Scheduling	A guide for estimating and scheduling of IAQ risk mitigation activities is provided to help contractors prepare accurate estimates and sequence plans.
5. Pre-Work Preparation	Steps taken to secure occupied spaces prior to construction mobilization are provided, in addition to actions needed during the transition from one phase of construction to the next.
6. Mobilization	A checklist for mobilization processes is includes the construction of temporary barriers, establishment of material paths, and the training of workers.
7. Construction Management	The management of IAQ risk prevention measures includes steps to protect materials from moisture, the detection and control of potential sources of moisture, dust control, temporary ventilation and pressurizations strategies, and mold abatement.
8. Closeout and Commissioning	Actions needed to ensure a smooth commissioning process are defined including the early involvement of commissioning agents, the start-up and testing of HVAC systems, and the training of building operations and maintenance personnel.
9. Certification	Practices to document and certify that an appropriate standard of care was implemented on the project are defined in efforts to enable the certification of construction projects for insurance and liability purposes.

IAQ, Moisture Control, and the Life Cycle of Buildings

The U.S. building industry is currently entering a panic mode regarding mold and IAQ risk during construction. A key research goal is a detailed analysis of potential sources of moisture during construction, and techniques to manage the subsequent IAQ risks.

Problem Definition

The air quality of a building is known to be important in determining occupant satisfaction, comfort, and productivity (Fisk, 2000; Wargocki, et.al, 1991;Milton, 2000). Although both organic vapors (formaldehyde, acetaldehyde, toluene, etc.) and bio-aerosols of various forms (bacteria, virus, protein-based allergens) are known, distinguishable, contaminant types, they are frequently related. That is, organic vapor odors frequently emanate from the presence of biological contaminants in building surfaces, e.g. the so-called mildew odor found in some buildings. The majority of the “difficult-to-solve” indoor air quality issues associated with a building can ultimately be traced to the presence of biological contaminants in building materials and/or the HVAC system.

The organic vapors and air-system-entrained biological species are the immediate contaminants, but the major, underlying contributing factor is often poor humidity control during the life cycle of the building - materials shipping to the site, materials handling at the site, materials exposure during construction, façade tightness in the completed structure, and HVAC temperature and humidity control during building commissioning and operation. Control of the environment, particularly air quality composition, within buildings is a life cycle issue, often related to humidity control during the life cycle.

Discussion: Moisture Control

Life cycle humidity control is so significant because of the requirements for growth and colonization of biological species. These requirements are: food source (carbon source) , moisture, adequate growth temperature, and spore seeding (Harriman, 2001). Most building framing and finishing materials are a food, carbon, source for biological species, particularly fungi. Dust found on these materials can also be a carbon source. Thus, metal surfaces of HVAC systems coated with a thin layer of dust can become a growth medium for fungi, which then become a growth media for other forms of fungi. Similar phenomena occur on concrete surfaces.

Fungal spores are present everywhere in outdoor and indoor air. It is not practically possible to prevent exposure of material surfaces to seed spores. Nor is it possible to use non-carbon containing finishing materials. Interior temperatures associated with occupant comfort are also optimal for the growth of many forms of mold and bacteria. One is left with the conclusion that life cycle humidity control is critical for the prevention of many indoor air quality issues in buildings.

The moisture activity or availability of a carbon containing building material is one of its important potential mold growing properties. The moisture activity of a material is its ability to release water, make water available to, a fungal colony that wishes to establish itself in the material. It is the material moisture content, rather than the immediate moisture content of the air, relative humidity, that influences fungal growth. Most building materials are desiccant - like, that is, they can absorb and hold water if exposed to high relative air humidity. They then make this held moisture available to the fungal seed spores that will inevitable find their way to the carbon source material. Also, any dust that is deposited on the material surface, will not only contain fungal spores, but will also be immediately position next to an available moisture source, if the material has been exposed to high relative humidity at some time.

Thus exposure of carbon containing building materials to high humidity conditions during shipping, on-site storage, building construction, or during building commissioning and operation will lead to fungal colonization. The “maturity” and number of colony life cycles, and the size of the mold problem will depend on sustained time at growth temperatures and the total available moisture in the carbon source material. The available moisture in the building material depends on time of exposure of the material surfaces to high humidity before, during and after construction. The risk of building IAQ problems is therefore directly proportional to the moisture availability in the building materials, and, therefore, to the humidity exposure of these materials during the building life cycle.

One is left with the following conclusion. One must control building materials exposures to elevated humidity (expressed either as %RH or dewpoints) during shipping, storage, construction and building operation, if one wants to measurably reduce the risk of development of building IAQ issues.

Suggested Strategy: Humidity monitoring and certification

From an operational point of view, this means preventing the exposure of building materials to elevated humidity, direct exposure to water or moisture sources, and minimizing the exposure to dust during the building life cycle. In practice this means sealed transport of building materials, controlled humidity storage at the site, minimal moisture exposure during construction, moisture tight façade construction, and controlled humidity operation of the building HVAC system at all times.

With the availability of low cost, portable, battery operated, temperature and relative humidity data loggers, and knowledge of the moisture uptake properties of specific building materials, one can envisage a system of traceable, documented, moisture exposure certification of all materials placed in a building system. The data logs would become a part of the building certification data. This would provide a type of data documented “certification” of minimized risk to fungal related IAQ issues for a particular building and perhaps even add to the building desirability from a potential occupant perspective.

FUTURE RESEARCH

Future Research is planned to investigate in depth the process which construction managers should consider in preparation and execution of hospital renovation and construction projects. Three primary areas of research have been identified:

Risk Assessment: All Guidelines for hospital construction strongly recommend that hospitals do an Infection Control Risk Assessment before launching a construction, renovation or demolition project.

Effectiveness of Methods to mitigate IAQ Risks: The concerns over mitigating the risk of spreading contaminants during a construction project at a health care facility continue to evolve. The regulatory requirements are expanding, and the governmental bodies responsible for approving the plans for proposed construction are more aware than ever before of the necessity to have a workable ICRA in place prior to beginning any work.

Effects of Practices on Productivity and Production: A lot of research has been done on preventing the infection spread during hospital construction, but there is no research done on effects of practices on productivity. Further research is recommended on this topic.

CONCLUSIONS

The number of patients who die from infections they contract while at the hospital has been reported to be as high as 90,000 per year. One cause of contracting these infections is known to be from contaminants spread as a result of construction projects. The design professionals, owners, contractors, and regulatory agencies involved in health care construction are the individuals responsible for understanding, executing, and enforcing the infection control measures required to reduce the infection rates. The result of these efforts will be a safer environment for the patients and staff who are treated and work in our health care system.

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