FUTURE RESEARCH NEEDS FOR MOLD GROWTH RISK ANALYSIS

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ABSTRACT

One of the major problems related to IAQ in residential and commercial buildings is microbial growth. Mold related problems in buildings are caused by complex interaction between biological behavior and physical building parameters. Although many involving disciplines have dealt with the mold occurrence in buildings for decades, mold related problems have not been lessened in modern building industry.

This paper reviews the characteristics of modern buildings with respect to mold growth and required considerations for reducing mold risk in different building project stages, i.e., the design, construction and operation stages. Modern buildings have introduced many new building materials, HVAC systems, and envelope systems. Since these changes can potentially increase mold growth risk, one needs to carefully check each material and building component in the design stage. Building system and usage parameters are the important parameters that contribute to the mold occurrence depending on the situation of the building. As an example, the effect of infiltration on mold risk is demonstrated in this study. The research community and building industry agree that the best way of reducing mold is to eliminate defects in the design and construction stages and proactively take care of the occupants' complaints regarding molds in the operation stage. The required consideration in all project stages is discussed, with special attention on the construction stage. It is found that, generally, an aggressive construction schedule produces higher mold growth risk than an IAQ conscious schedule.

There is an apparent need for reliable prediction and evaluation methods that can be used in design stage, for instance, to select appropriate building materials. Two on-going researches are discussed: the development of a performance indicator for mold growth risk and a design support system. Both are aimed at a better understanding of mold and moisture problems to inform decisions in the design stage.

1. INTRODUCTION

A major problem involving the indoor air quality (IAQ) in residential and commercial buildings is

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posed by microbial growth that occurs in certain (humid) conditions. To prevent microbial growth, local and international standards have set limits on indoor relative humidity (RH). However, an increasing number of publications have reported that such limits have not led to mold-free environment. Many modern buildings continue to suffer from mold growth, which is now regarded as a major health and liability issue in the building industry.

This paper reviews the characteristics of modern buildings with respect to mold growth and required considerations for reducing mold risk in different building project stages, i.e., the design, construction and operation stages. Although both the research community and building industry agree that the best way of reducing mold potentials is to eliminate possible defects in the design and construction stages and proactively take care of the occupants' complaints regarding molds in the operation stage, reliable prediction and evaluation methods that can be used in design stage have not been developed yet. Two emerging research approaches for these purposes are introduced.

2. OVERVIEW OF MOLD RELATED PROBLEMS

2.1 Causes and effects of mold problems in buildings

Mold leads to occupants' health complaints, defacement of building materials and structural damage of the framing members in buildings. These problems are caused directly by leaked water or high relative humidity in a building. Many studies have reported the possible causalities between building parameters and mold occurrences. Most interior dampness problems are usually related to construction faults, such as inadequate insulation, thermal bridges, inadequate ventilation, certain patterns of building use, interior sources of humidity, improperly weatherproofed outside walls, or inadequate drainage. Five main causes of mold growth in residential, commercial, and school building are illustrated in (Moon 2003a).

Mold can grow when relative humidity remains at a high level. The suggested critical limitations of relative humidity for mold growth vary across researchers. For example, the International Energy Agency (IEA) recommended an average relative humidity of 80% as being the critical threshold. Rowan suggested a local relative humidity of 75% as the limiting factor for fungal growth (IEA 1991; Rowan 1999). The required RHs for mold germination also vary with the species of mold and other environmental conditions, such as temperature, types of building materials, and required exposure time. Thus, one has to monitor the states of environmental conditions of building materials and indoor/outdoor conditions to prevent mold growth in a built-environment.

One of the biggest concerns in the building industry is health effects varying from runny or stuffy nose and scratchy throat, to eye irritation, and asthma. There is also widespread agreement that volatile organic compounds produced by many molds cause irritation of the nose, eyes and upper airways in humans.

2.2 Modern buildings and mold growth

To prevent moisture and water intrusion through the exterior, some modern buildings have adopted a moisture retarder in the envelope system. This has not proven to prevent molds as many modern buildings still suffer from moisture intrusion and high relative humidity. The causes of these problems can be related to the building methods introduced after the energy crisis in 1970's. Many new construction and interior finishing materials were introduced, such as paper fiber gypsum board, porous insulation materials, vinyl wall covering, pressed wood products, porous ceiling tiles, and textile wall and floor coverings. Some of these materials provide high nutrients for mold growth or retain water molecules inside the materials for a long time. Non-permeable floor or wall covering materials disallow water in wetted building components to diffuse through the wall and be removed by air conditioning system. From thousands of building materials available, architects are now faced with the problem to select the right combination of building materials to avoid mold related problems. Due to the complexity of mold growth phenomenon and the tight integration of different building systems, right material selection in the design stage is not easy without a help of a supporting system.

Most modern buildings have HVAC systems to condition air temperature and relative humidity. Inadequate operation and maintenance of cooling system could cause condensation on interior surface of building materials. In warm humid climates condensation occurs on walls, ceilings, and floors when their surface temperatures are cooled (by air-conditioning) below the dew point temperature of the surrounding air. If warm moist outdoor air infiltrates through the envelope wall (in a negatively pressurized building) condensation or dampness typically occurs on cool surfaces (e.g., wall paper, paper fiber gypsum board).

2.3 Characteristics of mold problems in buildings

Some buildings provide favorable combination of environmental conditions for mold germination including substrates (nutrition), temperature, relative humidity, and required exposure time. Every location of the building has different environmental states due to potential thermal bridge locations, stagnant air flow, air leakage, moisture production, and so on. These local effects and the particular usage of the building will determine the chance of actual mold growth in a building. For example, Mold prefers to grow where insulation materials are improperly designed or installed, which causes condensation problems due to thermal bridge effects. Other places for condensation include windowsills, corners between ceiling and exterior walls, behind impermeable wallpaper, and under vinyl flooring.

Because building system and usage parameters have different effects on mold growth based on the situation of the particular building, the effect of each parameter on mold growth risk should be made quantifiable. For example, infiltration of outside air through the façade of a building can increase or decrease mold growth risk depending on the climatological location of the building. To investigate the effect of infiltration on mold growth risk, a case study for a one-zone building was conducted through a one-year simulation using EnergyPlus. For the quantification of the mold growth risk analysis, the mold germination graph method introduced in (Moon 2003b) was used. In this study, two locations were compared, e.g., Atlanta and Hawaii. The building model includes a simple HVAC plant with a specified humidity ratio, a heating coil, and a supply fan. The HVAC system ran with an on-off control law and the zone temperature was set at 20 to 24℃ during working time (8:00 to 18:00). Case A represents the building without infiltration. Case B represents an infiltration of one air change per hour (ACH) in the building. For Atlanta, the risky days significantly decreased from 129 to 11 in case B. However, for Hawaii, the risky days increased from 71 to 108 as shown in figure 1. These results show that infiltration could increase or decrease mold growth risk depending on local yearly weather conditions. The effects of the full set of building parameters that dominate the physical and biological mechanisms of mold growth occurrences should be investigated to obtain more detailed results.

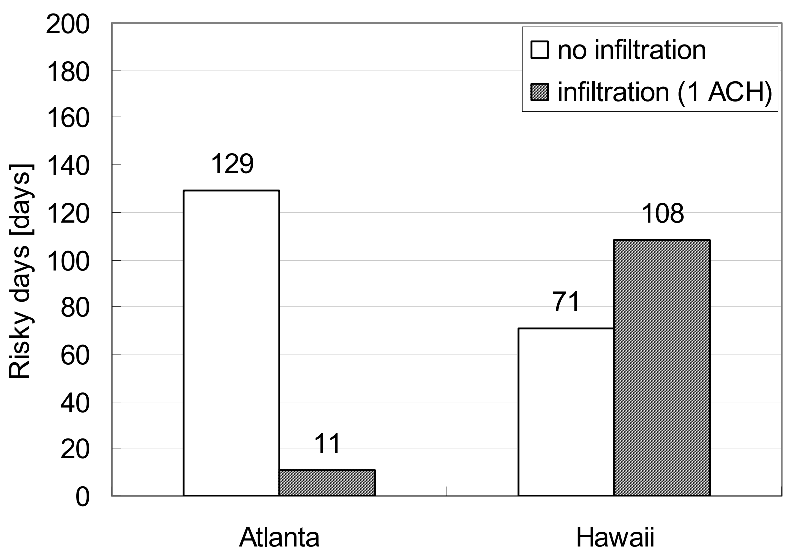

Figure 1. Effect of infiltration in two different locations.

3. REQUIRED CONSIDERATIONS IN BUILDING PROJECTS

Inspection and remediation of mold infested buildings once a building has mold related problems are not uncommon. And the number of litigation cases to settle the damages is increasing. The lawsuits and remediation procedures are generally brought after health injury and property damage already occurred. Both are expensive, take a long time in which the building is not operational, and do not guarantee mold free environment after the settlement. The best way is to eliminate possible defects in the design and construction stages and proactively take care of occupant complaints regarding molds in the operation stage.

3.1 Required considerations in design stage

Since modern buildings are complex systems with mechanical equipment (e.g., HVAC), it is hard to fix or replace building components after mold occurrence is detected. To avoid troublesome and painful remediation procedures, buildings should be designed and constructed with IAQ concerns. In the design stage of a building project, architects and engineers should carefully look at their building components, including ventilation system, envelop system, and finishing materials, to minimize mold growth risk. First, a ventilation system needs to be chosen to provide enough fresh air for occupants' health and reduce incoming mold spores through filter(s). Appropriate supply temperature and relative humidity should be provided by the system, with the aim to prevent germination of mold spores as well as to provide comfortable thermal conditions for occupants, according to a given size of the building and activity levels of occupants. The ventilation system should keep positive pressure across the envelope to avoid direct infiltration of humid outside air. Second, architects should carefully check that their envelop systems do not trap moisture inside multi-layered exterior wall, especially in cold regions. Inadequate location of vapor retarders and insulation materials in an envelope system can cause condensation as explained in (Kunzel 1998; TenWolde 2001). Impermeable wall covering materials on interior wall, such as vinyl wall paper, will not allow moisture migration to the indoor air and can cause condensation as well, which can lead to hidden mold contamination. Drainage systems should be designed carefully to prevent rain water leakage into exterior walls. Finally, selecting appropriate finishing materials is crucial for reducing mold growth risk. Some finishing materials provide a good nutrient for mold germination and some of them cause accumulation of moisture within a wall construction. Although the moisture accumulation in assembled wall system can be calculated by using hygrothermal models, application of these models routinely in the design stage is still limited and requires engineering knowledge to produce correct results.

3.2 Required considerations in construction and operation stage

All hygroscopic building materials have an initial moisture content after manufacturing. The moisture content in materials can vary depending on how they are delivered and stored on the construction site. This later affects to mold growth in the completed building. In the construction stage, managing building materials not to get wet or moist and using dried materials before sealing them into building structural component is important to reduce mold growth risk. Careful attention should be paid to the management of building materials on site, including the install sequences in different construction phases.

Generally, the actual construction process has three relatively distinct phases, i.e., “exposed”, “partially enclosed”, and “controlled.” (Poppe 2003) During the “exposed” phase of the construction process, moisture protection only applies to foundation and stored building materials exposed to the elements. The “partially enclosed” phase still cannot control moisture, but more careful management of storing building materials and installation procedure should be carried out because more porous and organic materials are used in this phase such as insulation materials. In the “controlled” phase, moisture intrusion from outside can be controlled and dehumidification by operating the installed HVAC system can be considered as an option in this phase. However, condensation due to incomplete insulation of building and negative air pressure can cause additional risk of moisture intrusion. Although scheduling the installation of finishing materials in the “controlled” phase and giving enough time for the wetted materials to dry are the right measures to reduce mold growth risk, one should consider the cost and benefits as well. Generally, an aggressive schedule that requires finishing interior to start in the “partially enclosed” phase produces higher mold growth risk as shown in figure 2. The moisture acquired in the construction stage will in most cases affect the mold growth risk in the operation stage.

Once a building is completed, the appropriate operation of the HVAC system and proper maintenance of the building should be carried out. The importance of the operation schedule of a ventilation system can be found in (Bayer 2001). Bayer observed many school buildings shut down the ventilation systems, including active humidity control system, over the weekends and vacations. The shut down period allowed the humidity to surpass 70% RH eventually leading to microbial problems in the schools. Preventive and corrective maintenance can also reduce occupants’ health concerns as well as property damage (Schoen 2001). Recommended maintenance activities related to controlling moisture in buildings were included in the addendums of ASHRAE Standard 62-2001. The addendum “62*m* “ covers operation and maintenance activities; the addendum “62*l*” covers construction and system startup for controlling moisture in buildings (ASHRAE 2001). Although this standard addresses the general issue of moisture control in buildings, more specific guidelines are required considering the location of buildings (climate) and outdoor air requirements.

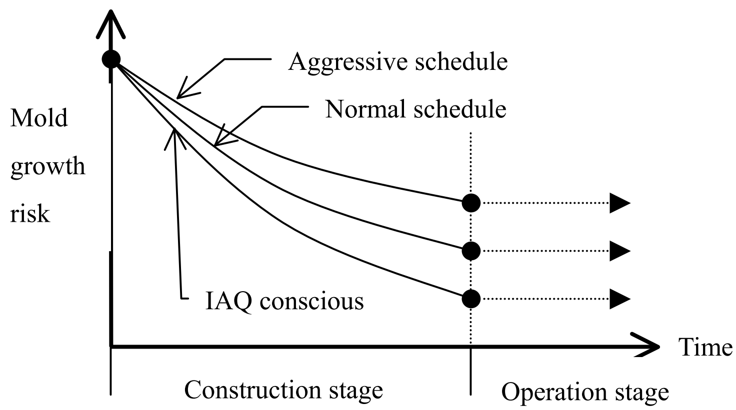

Figure 2. Mold growth risk and stages of building projects

4. NEW RESEARCH APPROACHES

Preventive actions to avoid mold infestation are still limited and supporting systems for architects, contractor, building owners and tenants are not well developed yet. Current research efforts have focused on the remediation methods and detecting mold problems in existing buildings. The two widely used guidelines on assessment and remediation are New York City and EPA guidelines (New York City Department of Health 2000; EPA 2001). New technologies also have been developed for sampling and identification of mold species, such as Microbial Volatile Organic Compound (MVOC), Polymerase Chain Reaction technique (PCR), and fungal detector (Morey 2002). It should be noted that these techniques and guidelines cannot be used for the evaluation or prediction of mold risk in design stages. To reduce adverse health effects and property loss, appropriate mold growth risk analysis methods and supporting systems for architects should be developed. Two emerging research approaches for these purposes are briefly discussed below.

4.1 Mold growth risk analysis methods using hygrothermal simulation

Recent research on favorable conditions of mold growth has revealed physical-biological relationships among relative humidity, temperature and mold germination. These relationships can be used to perform a “standard” hygrothermal simulation on a whole building scale and to assess mold growth risk in various locations of a building. However, the standard simulation is typically based on “idealization,” i.e. based on assumptions, which do not reflect the local, situational, and sometimes idiosyncratic aspects of building use and operation. To overcome these issues, a research work has been conducted to develop a performance indicator for mold growth risk avoidance in buildings, in which a comprehensive mold growth assessment is based on standard simulations augmented with a set of empirically evaluated cause factors (Moon 2003a; Moon 2003b). This new approach requires expansion of current simulation capabilities for more reliable mold growth risk analysis, shown in figure 3; each arrow represents one of the identified mold cause categories. The upper half relates to biophysical mechanisms driving the germination in existing buildings and the lower half of the figure relates to the detailed modeling of physical (heat and mass) transport mechanisms that result from special HVAC features and local 2D and 3D building details.

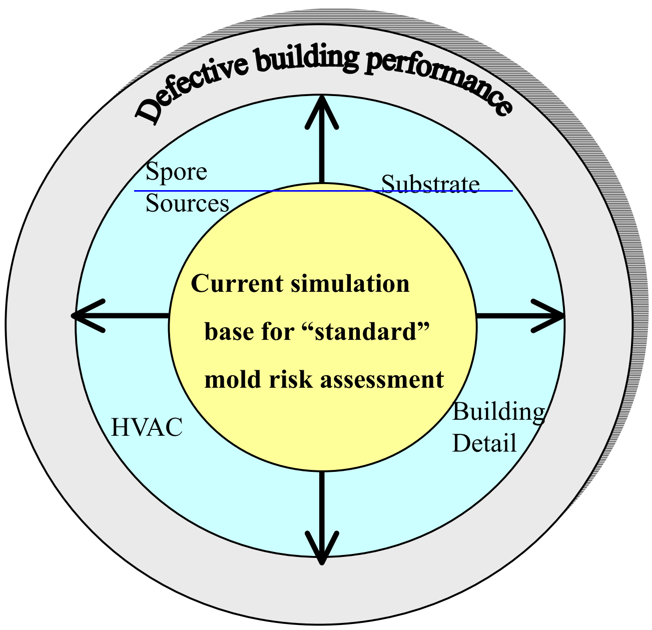

Figure 3. Additional simulation capabilities required for accurate mold growth assessments.

The research identifies a set of dominant parameters for mold growth risk per each cause category. A statistical parameter screening and ranking technique determine the parameters that have most important elementary effect on uncertainty in an extended mold growth risk analysis. The results of the screening are used to calibrate quantifiable "added risk" factors (cause factors) per cause category. This work will lead to the development of a comprehensive performance indicator based on standard simulation results and a set of additional "cause factors" that could explain unexpected mold growth occurrence with uncertainty. The resulting performance indicator will facilitate a more accurate prediction of mold growth risk at the design stages and provide effective control over the operation and maintenance of buildings with potential mold problems.

4.2 Design Supporting System (DSS)

Another research is to develop a design support system (DSS) that architects and engineers can use in the design stage to select appropriate building components and materials that reduce the potential mold growth. This research model, normative in nature, does not carry out the actual experiments, but works from a direct relationship between building properties and mold occurrence. In other words, it uses the relationship between the building properties to determine how they will contribute to mold occurrence. This model is based on the simulation results that are then cast into new knowledge, which reveals the causality between certain building properties and mold explicitly without having to go through lengthy simulation. This research tries to establish the relationships between certain building material properties and mold occurrence. A normative model can be generated by the statistic analysis of the simulation-created data and going through screening and causality finding, leading to the determination of parameters in an initially postulated formula based on the relationships found in the simulated models. This formula can be used as part of a DSS that will assist the facility manager and the building designer in making decisions on equipment selection and facility operation factors in order to avoid the risk of mold in buildings.

5. CONCLUSION

Mold related problems in buildings are caused by complex thermo-hygric-biological phenomena that involve studies in biology, chemistry, industry hygiene, environmental and mechanical engineering, and architectural engineering. Although each area of disciplines has dealt with the mold occurrence in buildings differently for decades, the research community agrees that the best way to reduce mold potential is to eliminate possible defects in the design and construction stages, and proactively take care of the occupants' complaints regarding molds in the operation stage. However, reliable prediction and evaluation methods for mold growth risk which can be used in design stage and for the selection of appropriate building materials have not been developed yet. Two on-going researches were introduced with these objectives in mind. They aim at the development of a performance indicator for mold growth risk and a design support system to be used in the design stage. These research efforts will provide a novel and more accurate method of evaluating and predicting mold growth risk and enhance the understanding of how building performance is affected by mold and moisture occurrences.

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