The Associations between Mold Remediation Practices and Post-Remediation Verification Testing for Residential Structures in Southern California from 2008 to 2019

A Dissertation Manuscript

Presented to the Faculty of the College of Health and Human Services

of Trident University International

in Partial Fulfillment of the Requirements for the Degree of

Doctor of Philosophy in Health Sciences

By

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Cypress, California

2020

Defended September 10, 2020

Approved by

Office of Academic Affairs

Month Day, Year

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Abstract

Background: Exposure to indoor dampness and mold is associated with an increased risk of poor respiratory health. In the United States, $3.5 billion is spent annually on asthma attributed to dampness and mold in homes, and one home, out of every 50 insured homes, files a water damage claim each year. Each of these claims involves incidents that introduce damp and moldy conditions into homes, and mold spores are aerosolized when damp and moldy building materials are disturbed during mitigation and remediation work. The consensus guideline documents, *ANSI/IICRC S500 Standard and reference guide for professional water damage restoration – fourth edition: 2015* [S500] and the *ANSI/IICRC S520 Standard for professional mold remediation – third edition: 2015* [S520], recommend training, work practices, and cleaning protocols to guide water damage mitigation and mold remediation work. The consensus guidelines also recommend evaluating the completion of projects by the use of a third-party assessment by an Indoor Environmental Professional, which includes air testing for airborne mold spores, physical evaluation, and visual assessment.

Objective: The purpose of this study was to determine the correlations between how closely water damage mitigation and mold remediation work follows consensus guidelines and the results of Indoor Environmental Professional assessments, especially mold spores.

Design: A nonexperimental, correlational design using secondary data was chosen as the ideal method to determine whether consensus guidelines were followed for water damage mitigation and mold remediation work.

Results: There was a significant correlation between how closely work followed consensus guidelines and the Indoor Environmental Professional (pass-fail) assessment ($p < .001$), with the greatest observed values between (fail + does not follow), (fail + partially follows), and (pass + does follow). There was also a significant correlation between the airborne mold spore count in the work area and how closely the work followed consensus guidelines ($p < .001$), with the mean rank for spore significantly higher when the work (does not follow) consensus guidelines. Moreover, there was a significant association between the airborne mold spore count in the work area and the Indoor Environmental Professional (pass-fail) assessment ($p < .001$), with the mean rank of spore for (pass) significantly lower than the mean rank for (fail).

Conclusion: Significant correlations were found between how thoroughly water damage mitigation and mold remediation work followed consensus document guidelines and the Indoor Environmental Professional assessment, especially airborne mold spore testing in the work area. As demonstrated in this study, the more closely mold remediation work follows consensus document guidelines, the more likely the project will pass post-remediation verification and airborne mold spore testing. Furthermore, fewer airborne mold spores in the work area were associated with mold remediation work that followed the consensus document guidelines, although there were significant associations between the manner in which the mold remediation work was performed, specifically, the use of explicit engineering controls. Water damage mitigation and mold remediation professionals that follow the consensus guideline document recommendations may reduce health risks to building occupants, while lowering disease burden and healthcare costs through effectively reducing the exposure to indoor moldy conditions following water damage mitigation and mold remediation work.

***Keywords*:** mold, spore, water, damage, restoration, remediation, ANSI/IICRC S500, ANSI/IICRC S520, indoor environmental professional

Preface

The scope of this study sought to identify a relationship between how closely water damage mitigation and mold remediation work followed consensus document recommendations and the successful outcome of a water damage mitigation and mold remediation project as evaluated by a third-party Indoor Environmental Professional. Many contractors employ methods and work practices described in consensus guideline documents that are widely accepted in the remediation industry, a general construction specialty. The validity of following some of these methods and practices has yet to be fully statistically quantified and before there can be an understanding of why contractors should follow consensus document recommended practices, first there must be an established statistically significant correlation between how the work is performed and the outcome of the project as evaluated by the Indoor Environmental Professional; hence, the execution of this dissertation research.

As an industrial hygienist who conducts indoor air quality evaluations following water damage mitigation and mold remediation work, the association between Indoor Environmental Professional assessments, which include air testing and how closely mitigation and remediation work follows consensus document guidelines, is a specific interest.

Acknowledgements

During the course of study at Trident University, my studies were interrupted several times with the unexpected loss of several family members, including my mother and brother. My husband, Stewart Robinson, was particularly encouraging during the difficult times. He reminded me that my educational goals were worth pursuing and that both my mother and brother would be proud of my accomplishment. The doctoral process has helped me grow as an individual and as a researcher. The dissertation process was a humbling experience, and the findings of this dissertation research are important in my professional life. I hope the findings lead to opportunities for additional study and eventual changes in the mitigation and remediation industries. Financial and health impacts of exposure to damp and moldy indoor conditions are monumental. I look to a future where public health advocates and contractors work together to reduce health risks for people in their homes.

Thank you to my dissertation chair, committee, and Trident University for helping me to realize my educational goals and helping position me to make a difference in the water damage mitigation and mold remediation industries. The principles of substance, rigor, and merit will be carried throughout my professional career and influence my non-professional life as well.

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Chapter I: Introduction

Indoor air quality should be improved following water damage mitigation and mold remediation work in residential buildings. The dissertation research sought to establish a positive association between how work was performed and the success of a project as evaluated by airborne mold testing and assessment by an Indoor Environmental Professional (IEP). Exposure to damp and moldy indoor environments are known to increase the risk of poor health outcomes for building occupants (Fisk, Lei-Gomez, & Mandel, 2007; IOM, 2004; Thacher et al., 2017; WHO-EUR, 2009). Water losses and elevated indoor humidity can cause damp and moldy conditions in homes (Crawford, Rosenbaum, Anagnost, Hunt, & Abraham, 2015; Harriman, 2012). In California, anyone can perform mitigation and remediation work without certification or training. A contractor license applies to construction work for compensation over $500 but does not regulate work with mold (California Business and Professions Code, 2005). There is no legislation in California that regulates mold remediation work practices, and there are no laws that require airborne mold testing or third-party assessment after the work is done to determine if the damp or moldy condition has been remedied (CDPH, 2019). Altogether, this means that workers without certifications or training can perform water damage mitigation and mold remediation work without formal guidance on work practices from consensus documents or other authorities. Two primary consensus documents exist for water damage mitigation and mold remediation (IICRC, 2015a; IICRC, 2015b). Both documents recommend work practices and training for workers, although the mold guidelines also recommend follow-up testing and assessment by a third-party IEP to validate that the damp and moldy condition was remedied. An important aspect to ascertain in this research was to determine if there was a statistically significant association between (a) following consensus document recommendations, (b) fewer airborne mold spores, and (c) passing assessment by an IEP. Lower airborne mold spore counts are presumed to represent better indoor air quality and a healthier indoor environment for building occupants. Health outcomes were not part of this study, and the focus of this research was the effectiveness of water damage mitigation and mold remediation practices.

Background

The prevalence of exposure to damp and moldy indoor spaces is high, and approximately one out of every 50 insured homes will file a water damage claim each year in the United States (Insurance Information Institute, 2020). Each of these instances inherently introduces a potentially damp and moldy condition to the home. Numerous hypotheses have been validated in research studies associating poor respiratory health with exposures in damp and moldy buildings (IOM, 2004; WHO-EUR, 2009). When affected building materials and furnishings are disturbed, mold spores can be aerosolized resulting in poor indoor air quality and an increased risk of exposure to airborne mold spores for building occupants (Harriman, 2012). In the United States, indoor dampness and mold are attributed to causing asthma in 4.6 million people, and roughly $3.5 billion is spent annually on asthma attributed to dampness and mold in the home. Sadly, there is a 30% to 50% increase in poor respiratory health outcomes for occupants of damp and moldy buildings (Mudarri & Fisk, 2007). While there are consensus documents to help guide water damage mitigation and mold remediation practices, there is a lack of research to determine whether following these practices align to successful mitigation or restoration projects. Moreover, there is a lack of legislation in California that recommends these best practices (CDPH, 2019).

Problem Statement

The health risks to occupants of damp and moldy buildings are well studied and documented, and it is known that workers and building occupants are exposed to airborne mold spores when water damaged and moldy building materials are disturbed (CDC, 2017; EPA, 1989; IOM, 2004; Johanning, Auger, Morey, Yang, & Olmsted, 2014; NIOSH, 2013; WHO-EUR, 2009). Therefore, the problem addressed by this dissertation study was a failure to embrace standard protocols, methods, and practices by the construction industry as a whole that possess the potential to reduce worker and occupant exposure to airborne mold spores resulting from water damage mitigation and mold remediation activities. Together, remediation industry leaders created best practices in the form of consensus documents, which if followed, would likely reduce the total counts of airborne mold spores remaining in the environment following mitigation and remediation while remedying the damp and moldy condition. Even further, the mold guidelines recommend third-party verification to validate that the damp and moldy condition was remedied. The dissertation research study validated that following practices described in consensus documents were associated with more successful projects and, therefore, reduced health risks for building occupants.

Knowledge gap. The two primary consensus documents that are used to guide mitigation and remediation work are the *ANSI/IICRC S500 Standard and reference guide for professional water damage restoration – fourth edition: 2015 [S500]* and the *ANSI/IICRC S520 Standard for professional mold remediation – third edition: 2015 [S520].* Upon comprehensive review of these documents, there were key sources and acknowledgments that identified numerous credible and empirical references. The references covered text and research that discussed health risks, remediation procedures, construction work practices, environmental microbiology, cleaning and restoration, worker safety, biological and chemical contaminants, and indoor air quality. However, an important missing component from these references was a study that validated the use of consensus documents as a guideline for successful mitigation and remediation. The consensus documents are American National Standards Institute (ANSI) certified and through a rigorous public review process, ANSI supervises the creation and development of guidelines and standards for many industries. The mission of ANSI stated as "To enhance both the global competitiveness of U.S. business and the U.S. quality of life by promoting and facilitating voluntary consensus standards and conformity assessment systems, and safeguarding their integrity" (ANSI, n.d.). The ANSI process of developing standards through consensus and public review goes a long way to validate the content of both documents. The documents cover worker training and certification, work practices and protocols, and the practice of recommending an IEP in post-remediation verification and clearance testing. As of 2020, the next logical step and pressing need was to demonstrate that following work practices and recommendations in the consensus documents correlates to fewer airborne mold spores and a passing assessment by an IEP. A successful project presumes a reduction in health risks from indoor dampness and mold for building occupants by remedying the damp and moldy conditions, although Johanning et al. (2014) acknowledged the limitations of assuming risk was reduced stating "Industry compliance and documented effectiveness are mostly unknown" (p. 97).

Purpose of the Study

The primary purpose of this research is to statistically validate the association between following work practices recommended in consensus documents for water damage mitigation and mold remediation and successful project outcomes. A successful project is represented as lower total airborne mold spore counts and a passing assessment determined through third-party testing by an IEP. Lower airborne mold counts imply a reduced exposure risk in related health outcomes for occupants of damp and moldy indoor spaces; however, health and safety were excluded from this study.

The dissertation study used existing post-remediation verification assessments and air testing reports from IEPs and contractors for residential projects completed in southern California between 2008 and 2019. The data included in the study represents reports from five unique IEPs and five different laboratories based on the work performed by eight different contractors. As such, work was an independent variable defined by how closely the contractor followed consensus document guidelines in performing remediation and mitigation work. Two primary dependent variables were spore (total airborne mold spore count in the work area) and pass-fail (the result of the IEPs assessment indicating completion of the remediation work). There were also additional independent variables included in the study that fell into three primary categories: (a) project characteristics; (b) engineering controls; and (b) environmental conditions. Analysis determined the influence of these variables on the outcome of the project. The research design was a nonexperimental correlational study that retrospectively examined the association between how work was completed, the project outcome as evaluated by the IEP, and total airborne mold spore count in the work area. The aim of the analysis was to uncover and measure the relationships between variables, not examine causation. In addition, the strength of relationship between additional predictor variables like temperature and relative humidity were explored. Because no centralized database exists, data were collected through a survey instrument and project reports provided by an IEP or contractor and manually input into a database. The variables were de-identified in the database to protect the identity of the IEP, contractor, laboratory, client, and property address. Data were kept on an external drive that contains all the raw data and reports included in this dissertation study.

Research Questions

The primary research question was aimed to determine if there was an association between how water damage mitigation and mold remediation work was performed and the project outcome as defined quantitatively by the airborne mold spore count in the work area and by the IEP physical assessment and reported response (pass-fail). First, the association between the pass-fail response and the total airborne mold spore count in the work area was examined. Then, the relationship between how the work was performed, spore count, and report results were investigated.

RQ1. Is there an association between the airborne mold spore count in the work area and the pass-fail assessment of the IEP?

Sub-RQ1. Will there be fewer airborne mold spores in the work area when the IEP assigns a passing grade?

RQ2. Is there an association between the airborne spore count in the work area and how closely the work follows consensus document guidelines?

Sub-RQ2. Will there be fewer airborne mold spores in the work area when work follows consensus document guidelines and more spores when work only partially follows or does not follow guidelines?

RQ3. Is there an association between the pass-fail assessment of the IEP and how closely the work follows consensus document guidelines?

Sub-RQ3. Will projects following consensus document guidelines pass more often than fail PRV by the IEP?

Altogether, the research questions represent the primary relationships that this study addressed to determine whether a statistically relevant association exists between the work practices recommended in consensus documents and the successful outcome of projects. Therefore, the analysis was an important step in producing data that justifies recommending the use of consensus documents for mold and water damage projects and likely reduces disease burden and healthcare costs indirectly.

Nature of the Study

The dissertation research was a nonexperimental, correlational study that used retrospective data. Data was collected from contractors and IEPs in the form of surveys, post-remediation verification and clearance reports, laboratory analysis reports, and chain-of-custody documents. The study used quantitative methods of data collection. One of the dependent variables, raw spore count in the work area, was measured on a ratio scale, whereas the other dependent variable, pass-fail assessment by the IEP, was measured on a nominal dichotomous scale. The assignment of how the work was coded based on project notes and photographs in the IEP reports. The analyses excluded health and safety data and consisted of correlations to determine the association between the variables and report the direction and strength of association.

Significance of the Study

A comprehensive review of the consensus guideline documents yielded numerous credible sources and acknowledgments and identified over 50 credible references. The references included scientific and technical articles, texts, and research, which focused on health risks related to mold and remediation, remediation procedures, work methods and practices, environmental microbiology, cleaning and restoration, worker safety, biological and chemical contaminants, and indoor air quality. The vitally important missing component from these resources, a study that validates the use of ANSI consensus documents as a guideline for successful mitigation and remediation, was needed since ANSI only develops the guidelines and uses public review to update guidelines but does not test the validity of the recommendations within the consensus guidelines. As a consequence, the validation of remediation work conducted per the consensus documents, including worker certification, worker training, and the use of an IEP in post-remediation verification and clearance testing, was inherently important. The consideration of whether consensus-guided work results in a reduction in health risk from airborne mold spores for building occupants is a direct, practical, and solvable public health problem. The dissertation research provided the novel first step to examine consensus guided work, mold spores, and use of IEPs, established the relationship between work practices and project outcomes, and measured the influence of individual engineering controls, characteristics of the loss, and individual worker training. Given the scope of this study, the impact of the results may be substantive in the form of public health position statements, the use of post-remediation verification and clearance testing, the mold remediation industry, and the insurance industry.

Definitions of Key Terms

Air filtration device. An air filtration device (AFD) is the same as an air scrubber. The appliance is used to clean or remove (scrub) particulate matter from the air through a series of filters (Bailey, 2005).

Clearance testing. Clearance testing is a term derived from the asbestos and lead abatement industries. It involves testing of air and surfaces for levels on a constituent (Brandys

& Brandys, 2008). In this instance, air testing for mold spores in the work area (affected), a non-affected area, and outside are included in the study.

Contractor. Contractor refers to the entity performing the water damage mitigation or mold remediation work. By trade, the contractor may be a general contractor, specialty contractor (remediator or other), handyman, or maintenance worker.

Indoor environmental professional. An Indoor Environmental Professional (IEP) is defined as an "individual who is qualified by knowledge, skill, education, training, certification or experience to perform an "assessment" of the fungal ecology of structures, systems, and contents at a job site, create a sampling strategy, sample the indoor environment…" (IICRC S520, 2015, p. 16).

Mold. A group of organisms that belong to the fungi kingdom. Often used interchangeably with fungi. The entirety of molds are fungi; however, not all fungi are molds (Dotson et el., 2004). Molds and fungi product and release millions of spores small enough to be airborne, waterborne, or insect borne. When humans are exposed to molds and fungi, negative health effects may occur in terms of allergic reactions, asthma, and other respiratory problems (Spellman, 2017).

Mold remediation. Mold Remediation is the process of remedying a moldy condition in a building following discovery of unsatisfactory conditions. Activities may include an overlap of water mitigation work coupled with cleaning practices and procedures designed to protect building occupants while moldy materials are removed or cleaned (Brandys & Brandys, 2008).

Post-remediation verification. Post-remediation verification (PRV) may or may not include clearance testing and represents the process of assessing the environment and remaining building materials following water damage mitigation or mold remediation (IICRC, 2015b). The evaluation should include a visual assessment to ensure that affected materials have been cleaned or removed and that general surfaces appear clean and free of debris (Hung, Caufield, & Miller, 2020).

Relative humidity. Relative humidity (RH) refers to the ratio of the amount of water in the air (Baily, 2005).

Spore. General term for a reproductive structure in fungi (Dotson et al., 2004). These seed-like structures are produced to create a future generation. Spores are adaptive and durable, surviving for long periods of time in the environment and vary widely in size and structure (Bailey, 2005).

Water damage mitigation. Water damage mitigation refers to the construction and clean-up activities that may follow a water loss to a building. Activities may include water extraction and material removal with structure and content drying (IICRC, 2015a).

Summary

Damp and moldy indoor spaces pose a threat to public health as well as a significant financial impact. Remediating damp and moldy spaces may increase the risk of poor health outcomes for building occupants. Industry related consensus documents exist containing recommendations on how to perform the remediation work while reducing the exposure risk to workers and building occupants. An association between how remediation work is performed and the outcome of the project through assessment and testing indicates that the use of consensus documents as a guideline to perform water damage restoration and mold remediation services produces more favorable project outcomes.

Chapter II: Literature Review

There is a long history of concern for the health of people occupying damp and moldy buildings. References to mold and unhealthy air from damp spaces dates back to centuries-old literature. In the book *Our homes, and how to make them healthy* published in 1883, the text describes "disease due to damp" and warns against disease that may result from occupying damp housing:

> In a word, the appearance of damp anywhere in a house, whether it show itself by direct evidence of moisture, by rust, by mold, is sufficient to indicate that the house is not in a condition compatible with the existence of health within its walls (Carter et al., 1883, p. 30).

Since Carter et al. (1883), numerous hypotheses have been validated in research studies associating poor respiratory health with exposures in damp and moldy buildings. While the health effects of mold exposure were outside of the scope of the current research study, it was important to discuss in brief the widely accepted theory on the subject.

Over the last 20 years, credible researchers have conducted and published meta-analyses and literature reviews that link poor respiratory health to conditions in damp and moldy indoor environments. The literature review contained herein briefly examines the meta-analyses and empirical studies that validate certain associations. While the dissertation study did not address the health effects experienced by building occupants, it is widely accepted that poor health outcomes result from exposure to damp and moldy indoor spaces. Water incursion events are the primary cause for dampness and mold in homes (Insurance Information Institute, 2020). When damp and moldy building materials and furnishings are disturbed, mold spores may be aerosolized resulting in poor indoor air quality and an increased risk of exposure to airborne mold spores for building occupants (Harriman, 2012). Given the present research sought to quantify airborne mold spores following remediation and mitigation activities and there were several methods to quantify airborne mold spores, a focus was placed on the use of spore traps, a non-viable sampling method, and other sampling methods explained in greater detail. Some states have indoor exposure limits to mold spores, but in California there are no indoor exposure limits set for airborne mold spores (CDPH, 2019). Historically, credible entities set limits for exposure; however, years later those limits were rescinded (Burton & Gibbins, 2011).

The mold remediation industry is a niche construction industry that focuses on water damage mitigation and mold remediation work. Two consensus documents are widely accepted in the industry and represent best industry practices. Worker training and certification is generally encouraged and consensus documents recommend the use of an IEP as needed to ensure mold remediation projects are successful (IICRC S520, 2015b). The data used in the current study were collected by an IEP. Some states have legislated the use of specific work practices and require certification for workers, contractors, and IEPs. Understanding the strength of association between recommended work practices described in consensus documents, total airborne mold counts, and the post-remediation IEP assessment was an important step to evaluate the value of following remediation work procedures.

Health and Exposure to Indoor Dampness and Mold

Nearly 90% of time is spent indoors, with approximately 19% of that time spent indoors in residential homes, whereas for infants and elderly persons, time spent indoors at home may increase to 95% (Matz et al., 2014). Indoor air quality is made up of many constituents, including gases and particulate matter. Particulate matter includes non-biological and biological particles that may be respirable. Mold spores and hyphal fragments are part of the microbiome found indoors (NASEM, 2017).

The U.S. Centers for Disease Control and Prevention (CDC) tasked the Institute of Medicine (IOM) with studying the relationship between poor health and indoor dampness and mold (IOM, 2004). The IOM published the findings in the 2004 book entitled *Damp indoor spaces and health*. Fisk, Lei-Gomez, and Mendell (2007) examined the IOM meta-analyses and quantitatively related a 30% to 50% increase in poor respiratory health outcomes for occupants of damp and moldy buildings.

In 2009, a World Health Organization book entitled *WHO guidelines for indoor air quality: Dampness and mold* was published. Like the IOM, WHO explored the relationship between poor health and exposure to indoor dampness and mold. Both IOM and WHO also concluded that there is an association between poor respiratory health and occupying damp and moldy indoor environments (IOM, 2004; WHO-EUR, 2009). Additionally, the CDC, the U.S. Environmental Protection Agency (EPA), and the National Institute of Occupational Safety and Health (NIOSH) published documents that directly relate moldy and damp indoor spaces to health problems (CDC, 2017; EPA, 1989; NIOSH, 2013). Billions of dollars are spent each year on water damage mitigation and mold remediation in homes all over the world. Smith and Katz (2013) provided data showing more than $838 billion was spent in the United States between 1980 and 2011 on weather-related water claims alone. In 2017, the ISO reported $13 billion in insurance payouts due to water damage (ISO, 2019).

In 2016, the National Academies of Sciences, Engineering, and Medicine (NASEM) published *Health risks of indoor exposure to particulate matter: Workshop summary*. In this book, the authors describe mold as a constituent in airborne particulate matter. Mold was identified as a pollutant and indoor environmental asthma trigger. Disturbing damp and moldy building materials can result in aerosolizing mold spores and increasing exposure risks to building occupants (Johanning et al., 2014).

The NASEM (2017) stated that damp and moldy indoor environments promote the ideal conditions for mold growth. Exposure for building occupants comes in the form of air from water damaged or moldy building materials. Sources of indoor dampness may be flooding, plumbing losses, human activities, roof leaks, excess indoor humidity, condensation, and poor ventilation. Each of these activities can lead to mold growth indoors.

Mendell, Mirer, Cheung, Tong, and Douwes (2011) conducted a meta-analysis of high-quality, peer-reviewed epidemiology studies published through 2009 on dampness, mold, and microbiologic agents and the respiratory or allergic effects. The researchers concluded that dampness and mold had consistent positive associations with multiple allergic and respiratory effects in both allergic and nonallergic individuals. There was a strong correlation between exposure and asthma exacerbation in children and exposure to indoor dampness and mold showed consistent correlation to increased asthma development and exacerbation in addition to a host of additional respiratory conditions and diseases.

The NASEM (2017) work entitled *Microbiomes of the built environment* concluded that occupants in damp buildings can be exposed to biological contaminants from deteriorating building materials in additional to airborne pollutants. The deterioration of building materials can be accelerated by the presence of dampness in the building. The results of the analysis produced a table of associations between health outcomes and exposure to damp indoor environments. Furthermore, the review of the IOM (2004), WHO (2009), and Mendell (2011) analyses presented sufficient evidence of upper respiratory tract symptoms, wheezing, coughing, and exacerbation of existing asthma due to dampness and deteriorating materials.

In a more recent study, Sinclair, Russell, Kray, and Vesper (2018) examined the association of indoor mold contamination and asthma risk in Hispanic communities in eastern Coachella Valley, California. The researchers acknowledged that many studies already established the association of increased asthma risk and respiratory illness with exposure to mold contamination and concluded that both the prevalence of mold contamination in homes and the incidence of occupant asthma was significantly higher in the Hispanic community of two cities in this geographic area of southern California.

One of the complexities related to mold exposure and health outcomes is the topic of toxicity and dose-response. Nearly any substance can be toxic (i.e., the substance need not be a toxic substance to be toxic to an organism). For instance, water is a common and abundant substance vital to life on earth, but water toxicity can occur in some conditions. If a person drinks too much water too quickly, bodily fluids become too dilute, resulting in tissue damage and even death (Bailey, 2005). Toxicity after mold exposure is related to mycotoxins that may be produced by active mold colonies. Mold toxicity through mycotoxins is generally associated with contamination of food and food products and this type of toxicity results from ingestion of contaminated food, which can cause extreme illness or death. The toxicity from airborne mycotoxins and the dose-response of mycotoxins are less well understood as some people appear to be susceptible to toxicity while others experience a mere allergic response (Bailey, 2005). Mycotoxin exposure can be oral, dermal, or inhalation and produce an acute or chronic health effect, and although testing for mycotoxins is not common, at least one study detected one of seven mycotoxins in 66% of samples from mold contaminated building materials (Plog & Quinlan, 2012). However, no mycotoxins were detected in samples collected from indoor environments with no water damage. In nature and under laboratory conditions, potentially toxigenic fungi fail to produce mycotoxins consistently, and there are a number of poorly understood contributing factors to mycotoxin production, including available water and food. To further complicate the discussion of mycotoxins, it is important to note that a specific mycotoxin may be produced by more than one species. Spore inhalation is considered the most common exposure route for mold-related illnesses. Yet, toxin producing mold spores are sometimes not detected in air samples when mycotoxins are present in water-damaged building materials. Therefore, it is possible that spore counting may under-represent actual mold exposures for building occupants.

A number of case studies and metanalyses explored individual responses to mold exposure and clearly identified the relationship between exposure and disease. While the dose and susceptibility are not well understood, strong correlations exist between exposure and disease. Few studies have been conducted that follow health outcomes after remediation work is completed for building occupants exposed to mold contamination. Patovirta, Meklin, Nevalainen, and Husman (2004) studied the health effects of mold exposure on 56 teachers in three mold damaged schools in Finland. The teachers were given a questionnaire to complete after exposure and before remediation work began. The same teachers were given a questionnaire one year following the completion of remediation work. Allergic rhinitis, sinusitis, conjunctivitis, and fatigue were reported by the teachers in the initial survey at a higher incidence that the general population. One year after remediation work, there was a significant reduction in the incidence of headache and fatigue while respiratory symptoms persisted for longer and needed more time for remedy, whereas the identified risk factors for poor health effects included age, gender, time of exposure, length of time employed at the school, and atopy. Additional case studies on pre- and post-remediation symptoms for building occupants are needed to understand the long-term effects of mold exposure.

Moisture and Indoor Mold Growth

Fungi require a food source and water to grow, and wet and damp building materials provide the necessary conditions for mold colonies to thrive. For instance, wet cellulose-rich products like gypsum board provide the perfect conditions for mold growth indoors (Arumala, 2007). Given the wide array of building materials that could become wet or damp, and the growing incidence of remediation work, Bailey (2005) published, *Fungal contamination: A manual for investigation, remediation, and control,* in an effort to provide some direction to the growing industry of remediation and mold assessment. Baily (2005) cited a widely growing and recognized problem that culminated at the end of the 20th century with a growing concern and fear of indoor mold growth in buildings, but by the early 21st century, there were thousands of mold-related insurance claims and mold related lawsuits. The Bailey (2005) text provided a comprehensive guide to mold growth within a building, but the author was careful to state that mold itself was not the problem, but rather a symptom of the real problem (i.e., moisture).

Mudarri and Fisk (2007) estimated that 20 to 50% of homes have one or more signs of dampness. Water activity in the substrate is the primary environmental condition that allows mold to colonize, and water activity is the amount of “free” water available to microorganisms. Numerous building materials possess a water activity that allows for fungal species to colonize. Adams and Mendell (2019) described why water activity matters and how it is related to mold growth. Microbiologists studied individual mold species and devised various methods to estimate the amount of water activity required for species to colonize. Some molds are capable of growing in relatively dry conditions, while other molds, like *Stachybotrys,* require high water activity at nearly 95%, although most molds require a water activity at more than 70% to colonize (Adams & Mendell, 2019). In this article, the key to preventing mold growth was to identify excess moisture and remedy the cause before fungal colonization initiates. The typical tools for measuring water activity in building materials are pin-moisture meters and pin-less meters, but the lack of standardized meters, readings, and interpretations present a substantial problem when evaluating the water activity of building materials. For example, wood may have a moisture content range depending on the wood type, but drywall may have a different water activity altogether. While moisture meters are the most common tools used for evaluating the condition of building materials, inconsistency makes the meters unreliable as the sole method for evaluating dampness in a building (Adams & Mendell, 2019).

Water activity is used to classify molds into groups representing xerophilic, mesophilic, and hydrophilic species (Hung, Miller, & Dillon, 2005). Knowing the minimum water activity needed for mold growth can be useful when evaluating mold contamination. Between the time a water incursion event or a damp condition is noted, wetting and drying may occur over an extended period. Because mold species thrive and grow at different rates and with different water activity needs, species of mold may be present from each of the three categories. The amount of water and the length of time the water was present contribute to the species present and the species colonization. Mold species can also be related to optimum temperatures, although moisture is more important to the evaluation and control of indoor mold (Hung, Miller, & Dillon, 2005).

In the book by Hung, Caufield, and Miller (2020) entitled *Recognition, evaluation, and control of indoor mold,* moisture problems in buildings are separated into five categories. Each of the categories has characteristics that lead to specific mitigation measures to prevent building dampness and resulting mold growth: (a) rainwater or groundwater, (b) plumbing water, (c) condensation, (d) water vapor sources, and (e) installed damp building materials. Several methods by which water and moisture are transported in addition to the sources were explored with a gravity and pressure difference inherent to liquid flow, which is common in plumping leaks or water incursion events that originate on an upper floor or a roof. Water not only damages materials at the event, but also damages materials below. The capillary suction of liquid is the primary way that water enters porous building materials like drywall and standing water may be just a few inches deep, but capillary suction will wick water up 12 in. (30.48 cm) or more in a material like gypsum board (Hung, Caufield, & Miller, 2020). Air currents may move water vapor from one area to another like in an attic, and the moisture transport may result in a damp condition away from the source of the moisture. Improper ventilation or the lack of exhaust ventilation can also be the cause of water vapor diffusion. When relative humidity exceeds 60% indoors, excessive moisture can build up and provide suitable conditions for mold growth (Hung, Caufield, & Miller, 2020).

In an effort to illustrate the value of ventilation as it relates to indoor relative humidity, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) included guidelines for indoor humidity in the standard on *Ventilation and acceptable indoor air quality in residential buildings*. Historically in this standard, indoor relative humidity was expressed in a percentage with recommendations to keep indoor humidity between 30% and 60% to reduce microbial and other biological growth (ASHRAE, 2019). The standard now expresses humidity as dew point in an effort to address condensation that often occurs on surfaces (ASHRAE, 2019). Condensation can occur when surface temperatures reach dew point and the dew point is the temperature reached when ambient air cools to the point of oversaturation and water droplets can form on surfaces (Hung, Miller, & Dillon, 2005).

The key to reducing exposure to indoor mold growth is to eliminate moisture problems. Moisture is needed for mold spores to germinate and colonize. Uncontrolled humidity, lack of adequate ventilation, direct water loss including roof leaks and plumbing losses, and indirect water loss like improper drainage and migrating ground water can all contribute to conditions conducive to indoor mold growth (Spellman, 2017).

Methods for Measuring Indoor Mold

In their meta-analysis on the health effects of indoor dampness and mold on children, Kennedy and Grimes (2013) discussed the lack of consistent tools to measure and assess moisture and fungi in the built environment. The primary methods used include the U.S. Environmental Protection Agency's preferred method of ERMI, viable air sampling, and the slit impactor or spore trap. There are different analyses that correspond to each type of sampling.

Post-remediation verification sampling. The use of PRV sampling is commonly performed as a quality control and quality assurance method when remediation work is completed (Hung, Caufield, & Miller, 2020). The PRV sampling is coupled with a thorough evaluation of the work area, including a visual assessment to ensure no damp materials remain in the affected area. Furthermore, moisture meters are often used to determine the moisture content of remaining materials. During the assessment, no visible mold-impacted materials should remain, which includes water stained items and suspect growth on building materials. Each surface in the work area should have been cleaned or removed and sampling can include a surface sampling of any surface. It is recommended that building occupants are notified, and air sampling is conducted on a tripod or elevated above surfaces closer to the breathing zone. Sampling number is recommended at a minimum of two to provide the opportunity to evaluate variability in repeated measures. Samples may be collected in the work area and outside of the work area.

Brandys and Brandys (2008) described the process of post-remediation sampling in the publication entitled *Post-remediation verification and clearance testing for mold and bacteria– Second edition.* The PRV protocol should be customized for each project based on size, complexity, and exposure risks. With the understanding that there are an increase in adverse health risks associated with exposure to indoor dampness and mold, the IEP should consider what is necessary to reduce the risk in consideration for health, potential litigation, and legal liability. As such, these goals in consideration with documentation that the affected area has been restored to a pre-loss condition and client cost constraints are also part of the PRV plan. The ultimate goal of a mold remediation project is to ensure normal fungal ecology. Therefore, an IEP evaluation and sampling should be sufficient in scope so that the appropriate data are present to validate the presumed normal fungal ecology. Without the benefit of exposure limits or normal or acceptable levels of mold, simple comparisons from samples collected in the work area with ambient indoor and outdoor samples are recommended.

The AIHA (2004) published guidelines that briefly described post-remediation verification. Air sampling was recognized as a secondary tool in PRV, preceded by visual assessment and inspection of the affected area, although the AIHA (2004) also included responsibility to ensure that the course of the moisture is remedied. Airborne mold spore sampling, whether qualitative or quantitative, is to be employed as needed with the following considerations: (a) no specific guidance exists to universally evaluate indoor airborne mold spores; (b) airborne mold spore levels vary with environmental conditions, time, level of mold growth indicators, and location; (c) sampling is one tool for evaluation; (d) airborne mold sampling may be useful in determining the level of contamination in adjacent spaces; and (e) there are limitations to each type of sampling.

The Indoor Environmental Standards Organization (IESO) produced *Standards of practice for the assessment of indoor environmental quality* in (2003) in an effort to provide guidance for mold sampling and assessment of mold contamination. Included in the reference guide were sampling methods for slide impactor, viable impactor, culture media, dust and surface sampling using vacuum filtration, and surface sampling with wetted swabs and clear adhesive tape.

Environmental relative moldiness index. The U.S. EPA developed the Environmental Relative Moldiness Index (ERMI) scale in an effort to quantify mold contamination in homes. The sampling comprises collecting composite dust samples with analysis by a DNA-based method known as Mold-Specific Quantitative Polymerase Chain Reaction (MSQPCR) (Kamal et al., 2014). The ERMI value is not consistently associated with visible mold, although the ERMI value is higher in homes with reported moldy odors. In the study by Reponen et al. (2010), air and dust sampling was conducted simultaneously and there was no significant association between the total spore counts in the air samples and the ERMI value of the dust samples. The authors suggested that additional research was needed to determine which assessment method, if any, will be useful in assessing risk factors for the development of asthma. Sinclair et al. (2018) used the ERMI scale to quantify mold contamination in homes and the ERMI values in the study were in the top 25% of ERMI values for homes in the United States, although the ERMI values were not attributed to airborne mold spores or water incursion events.

Andersen N6. The Andersen N6 sampler uses a sampling pump to draw air into a collection plate that is prepared with malt extract agar (MEA), of which all the drawn airborne particles impact the collection plate. Then, the collection plate is prepared in a laboratory, the viable mold spores grow on the MEA as a food source, and the resulting colonies are identified and quantified. The results are viable colony forming units (CFUs) as a total and per mold type (Kleinheinz, Langolf, & Englebert, 2006). Although Andersen N6 has merit, there are limitations to this viable sampling method. For instance, the capture medium is commonly an agar plate; however, some mold types colonize more readily on malt extract agar (MEA) or potato dextrose agar (PDA). Still, some fungi are better colonized on dichloran glycerol agar (DG-18). Individual colonies growing on the plate are reported as colon-forming units per cubic meter or (CFU/m^3), but spores that do not colonize are not identified in this sampling method. Another limitation is climate conditions such as dehydration and freezing temperatures that affect the ability of spores to impact sufficiently on the media, which may result in an omission or under-reporting (Brandys & Brandys, 2006). An additional limitation is the use of multiple-hole impactors as the approach each laboratory uses for analyzing samples. Laboratories employ various proprietary and customized processes for growing cultures and counting, and some of these laboratory methods underestimate concentrations (Willeke & Macher, 1999).

Electrostatic dust collector. The electrostatic dust collector (EDC) has been used in comparison with the viable sampling methods to assess airborne mold contamination, but the EDC has been used reliably to analyze other bioaerosol including endotoxins, allergens, and microbial DNA. Normand et al. (2016) recognized the lack of reliable tools for measuring indoor mold contamination through sampling. The lack of standardized methods for sample collection, varying environmental conditions, and indoor air fluctuation, taken together, present problems. The EDC method has been shown to provide a relatively accurate profile of indoor airborne molds and possibly provide a more representative assessment.

Slit impactors and spore trap sampling. Pityn and Anderson (2011) published a study on the use of slit impactors for airborne fungal enumeration, which is typically referred to as spore trap sampling. Slit cassettes and low volume flow pumps are utilized to capture aerosolized particles that include mold spores and there is no regard for viable (living) or non-viable (non-living) spores, but rather the spore type is identified and enumerated through the use of transmission light microscopy. The spore trap sampling method is fairly simple with the analysis as a visual identification and enumeration under a microscope by an analyst. Not only is this method provide ease of sampling and analysis, but it is also inexpensive, which taken together, these characteristics are important considerations for public health policy makers.

In the IESO (2003) *Standard number 1210: Standard practice for sampling mold in air using a cassette slide impactor,* a chain of custody was indicated to provide a recorded history of the custody of the sample including signatures for all the individuals who handled the sample. Laboratories analyzing samples should be accredited by a recognized agency as following the ISO 17025 Standard. In the United States, the National Institute of Standards and Technology (NIST) is responsible for the lab accreditation program known as the National Voluntary Laboratory Accreditation Program (NVLAP). The NVLAP provides third-party accreditation to testing and calibration laboratories (NIST, 2017). Direct microscopy is the method of analysis best suited for non-viable, spore trap sampling and calibration is recommended for vacuum pump sampling, including the use of a rotameter and a primary flow meter with NIST traceable standards. Following flow meter calibration, the pump flow should be adjusted to 15 L per minute for Air-O-Cell™ cassettes. The time recommended for sampling varies from one minute for highly active environments to five minutes for active environments, and 10 minutes for calm environments. Samples should be handled according to ISO standard 17025, but there are limitations to this sampling method. For example, it is not possible to culture spore trap samples and some mold types cannot be identified through direct exam analysis, which requires culturable sampling and slides that are overloaded with particles often resulting in underrepresentation of spores (IESO, 2003). Much of the IESO Standard Number 1210 was derived from methods described by Willeke and Macher (1999) in *Bioaerosols: Assessment and control,* which provided one of the first widely used guides for air sampling, particle collection, equipment calibration, and equipment selection.

Godish and Godish (2007) conducted an important evaluation of collection methods for counting total airborne mold spores. Using an air sampling pump with a calibrated mass flow meter and slit impactor cassette, the study evaluated the accuracy of the pumps, cassettes, and mounting film. Each cassette contained a glass slide that was coated with a sticky substance. When air was drawn across that slide, airborne particles impact and adhere to the surface. Then, the slide was viewed by an analyst under magnification and the total spore count (enumeration) and spore type (identification) were reported. The study failed to find a significant difference in total spore counts between sampling pumps and, in general, the spore counts and particle counts were similar for the different types of cassettes. However, magnification changes did show differences in total spore counts with an analysis at (1000x) yielding the best total airborne counts, while magnification at the lowest measurement of (400x) yielded an unacceptable under-reporting of total mold spores. There appeared to be no difference in the type of adhesive used on the slides. The Allergenco cassette, compared to the Burkard sampler, yielded significantly higher total molds for concentrations (1.2x), and the Air-O-Cell™ cassette also yielded significantly higher counts than the Burkard sampler (1.4x). However, the total spore count differences observed between cassettes was not as significant as the difference in total for counts observed when magnification changed (Godish & Godish, 2007). A more recent similar study was conducted wherein seven different laboratories analyzed the total spore count for four different slit impactors. The study results did not indicate a statistically significant difference in spore counts between cassettes (Robertson & Brandys, 2011). Godish and Godish (2007) revealed an area that should be explored further, given that analysis is typically conducted by a third-party laboratory analyst certified in environmental microbiology, although there is no requirement for the level of magnification used. When laboratories use (400x) and not (1000x) magnification, under-reporting of spores is likely possible, which may indicate a remaining, yet undetected, risk to building occupants, hence the need for additional research in this area.

Viable versus non-viable. Many airborne mold spores are dead, and it is estimated that nearly 90% of airborne *Stachybotrys chartarum* mold spores are dead, which means that the spores will not grow; hence, the spores are not viable (Plog & Quinlan, 2012). However, the dead spores are almost certainly still toxic and if only viable sampling methods are utilized in the assessment of a *Stachybotrys chartarum* contamination, the total count of species spores present may be under-represented. Different species require different growth media and conditions to colonize and when the media selected (i.e., malt extract agar) is not preferred by the species present, colonization in the laboratory will not occur and a species will not be identified or quantified in the laboratory report.

In the article by Kleinheinz, Langolf, and Englebert (2006) entitled "Characterization of Airborne Fungal Levels after Mold Remediation," the authors evaluated the practice of "clearance testing" following mold remediation projects. The purpose of the study was to evaluate the use of clearance testing as a tool for determining the effectiveness of mold remediation projects (Kleinheinz, Langolf, & Englebert, 2006). Anderson sampling is commonly referred to as viable sampling because only spores that will grow are analyzed and these spores are viable under the right conditions. Spore trap sampling is similar in that it also uses a pump to draw air across a medium. In the case of the spore trap, no culturable methods are used and instead a sticky substance on the slide inside the spore trap cassette captures all the particles and spores are then identified by type and enumerated. Results are presented in raw counts, spores per cubic meter of air (spores/m^3), and percentage of each mold type. The spore trap method accounts for all airborne mold spores, whether they are viable. Kleinheinz, Langolf, and Englebert study (2006) used both methods of collection and analysis that were performed following mold remediation. Sampling occurred in the complaint area (work area), a non-complaint area (non-work area), and outside. For each project, the results from viable sampling were compared to the results of non-viable sampling using paired *t*-tests. The mean difference between the results of the testing in each of the three areas sampled were used to determine if there was a statistically significant difference and the process was repeated for each testing method. One important aspect to note is that the two testing methods were not compared to one another. For both testing methodologies, the airborne fungal levels in the complaint area were statistically different that the non-complaint area sample and the outside samples leading the authors to determine the projects were successful in mold remediation. In viable sampling, projects deemed not successful showed insignificant differences between sampling results in complaint areas and outside. In non-viable sampling, the projects deemed non-successful showed insignificant differences between sampling results in complaint areas, non-complaint areas, and outside. Kleinheinz, Langolf, and Englebert (2006) concluded that airborne fungal sampling added value to the list of procedures used to determine the success of remediation projects. There were also similarities in the results of both viable and non-viable methods of airborne fungal sampling and, collectively, the use of both sampling methods increased the validity of the results to ascertain whether a mold remediation project was successful or not successful. Noteworthy is that elevated levels of viable mold spores may indicate that a hidden mold reservoir exists as the source of amplification if no visible suspect growth is present without consideration for viable or non-viable testing methods. The authors recommended airborne sampling for mold following all remediation projects, and this recommendation is consistent with recommendations contained in consensus documents on mold remediation. The AIHA and the ACGIH recognize the use of post-remediation air sampling for mold spores as part of a comprehensive assessment for mold contamination following remediation work (Hung, Caufield, & Miller, 2020; Hung, Miller, & Dillon, 2005; Willeke & Macher, 1999).

Hung, Miller, and Dillon (2005) recommended caution when interpreting spore trap data. The primary advantage that non-viable samples have over viable samples is time. Cost is also a factor, but the time to culture viable sampling can be 10 to 14 days as colonies grow, while non-viable sampling can be calculated immediately. The use of non-viable sampling as a stand-alone tool is discouraged and inconsistency in laboratory standard operating procedures can affect laboratory reporting, whereas housekeeping, ventilation, and air movement can affect spore trap sampling. Without visible assessment and inspection, it is not possible to determine how well the results of airborne sampling for mold spores correlates to building damage.

Exposure Limits

Elevated levels of airborne mold spores are associated with an increased risk for poor respiratory health. Studies have validated a positive relationship, but a dose-response relationship is not well understood. Several health conditions have been associated with mold exposure, and several reaction types from mold exposure are known. Different spore types and species are associated with some responses and not with other responses. Mold is ubiquitous as very few indoor environments are free from airborne mold spores. Permissible exposure limits or PELs that quantify safe levels of indoor airborne mold spores do not exist for residential properties (Burton & Gibbins, 2011). According to the California Department of Public Health, "Science-based exposure limits for indoor molds cannot be established at this time, and none exist in California" (CDPH, 2019).

Modern exposure limits for airborne mold spores were first proposed in 1988, and most were published by 2002. A number of difficulties arose in the development of limits, and a number of factors contribute to the variability of mold spore levels in the atmosphere. Mold levels are affected by air movement, environmental conditions, species, particle size, and particle shape. Analytical variability of mold sampling methods can be higher than 25% depending on the monitoring methods and sampling methods that are employed (Brandys & Brandys, 2006).

Remediators and indoor environmental professionals are left without adequate tools to evaluate the health risks present following a water loss. Consensus documents recommend that remediators follow work practices that minimize amplification of airborne mold spores and contain the amplified spores. Indoor environmental professionals collect air samples in the work area and then, the samples along with a chain of custody are sent to a laboratory for analysis. The analyst qualifies and quantifies each sample, recording the total number and type of airborne mold spores present in both raw count and (spores/m^3) at the time of sampling. Each IEP has criteria for evaluating the success of a project and part of that criteria is the result of air sampling for mold spores (Kleinheinz, Langolf, & Englebert, 2006).

Without exposure limits, there is a “less is better” approach to evaluation. Remediation projects with fewer airborne mold spores in the work area may equate to a decrease in health risk for building occupants. However, it may not be possible to establish exposure limits due to the ubiquitous nature of mold, the lack of established dose-response relationships, and individual susceptibility. Therefore, more studies are needed to validate this hypothesis.

Consensus Documents

The objectives of water damage mitigation and mold remediation work are to restore a pre-loss condition and return the affected area to normal fungal ecology through removal of visible mold and mold contaminated materials, removal of airborne mold spores through the use of air filtration devices, and cleaning mold growth and remnants of mold growth from remaining building components and surfaces (Brandys & Brandys, 2008). The two primary consensus documents that are used to guide mitigation and remediation work are the *ANSI/IICRC S500 Standard and reference guide for professional water damage restoration – fourth edition: 2015 [S500]* and the *ANSI/IICRC S520 Standard for professional mold remediation – third edition: 2015 [S520].* The consensus documents are American National Standards Institute (ANSI) certified and through a rigorous public review process, ANSI supervises the creation and development of guidelines and standards. The ANSI mission is “To enhance both the global competitiveness of U.S. business and the U.S. quality of life by promoting and facilitating voluntary consensus standards and conformity assessment systems, and safeguarding their integrity” (ANSI, n.d.). The ANSI process of developing standards through consensus and public review are used validate the content of both documents, which cover worker training and certification, work practices and protocols, and the practice of recommending an indoor environmental professional in post-remediation verification and clearance testing.

The S500 is a professional standard intended to guide contractors performing water damage restoration work. The standard contains principles of water damage, restoration and guidance in building and material science, psychrometry, health and safety, and risk management. The recommendations are provided to guide successful water damage restoration, prevent the amplification of microorganisms that may be present, and reduce the likelihood of mold growth. Through the implementation of assessing water loss and resulting damage, the manual provides guidance for water extraction, material removal, psychometry to dry remaining building materials, and guidance to recognize hazards such as mold growth, asbestos, and lead. A focus on worker training and certification guides the restoration process. The standard provides general construction industry best practices with specific knowledge of water damage assessment and mitigation methods. The use of specialized experts are recommended when specialized skills are required. Of particular interest is the recommendation to collaborate with an IEP when water loss results in the proliferation of microorganisms. The IEP may be engaged for the assessment of sewage or other microbial contaminations, public health issues, when there is concern for adverse health effects, and for post-remediation verification.

The S520 is a reference guide for mold remediation work. The standard discusses recommendations for work practices, engineering controls, contractor qualifications, health and safety, indoor fungal ecology, health risks from exposure to indoor mold, and the use of IEPs in evaluation and post-remediation verification. The standard includes worker training and certification in specialized mold remediation skills and evaluation of affected materials and appropriate methods for treatment are discussed. At the heart of this standard are key principles that guide worker protection and building occupant protection such as the use of engineering controls including containment, decontamination chamber, negative air, air filtration devices, HEPA vacuuming, use of encapsulants, use of antimicrobials and biocides, and post-remediation verification assessment by an IEP. Chapter 12 of S520 is dedicated to the IEP and assessments. Contained therein are recommended guidelines for a qualified IEP including education, knowledge, skills, training, and field experience. Field of study for the IEP include indoor environmental quality, water damage restoration, occupational health and safety, building science, systems maintenance and operation, mold remediation, and construction failure. The IEP may help the remediator assess the loss and develop a scope of work based on principles described in the S520 standard. Depending on when the IEP is contracted to engage in a project, the IEP may conduct project monitoring during remediation work, or the IEP may assess the project at the completion of remediation work and before reconstruction. The IEP assessment includes a visual assessment, physical assessment, and sampling for airborne mold spores.

Many of the work practices and procedures contained in the IICRC S500 and IICRC S520 were previously part of other guidance documents, including the ACGIH work entitled *Bioaerosols: Assessment and Control* (Shaughnessy & Morey, 1999). Prevention is the key factor described and there is a focus on identifying and controlling sources for mold growth, especially moisture. When microbial contamination occurs, removal is recommended and porous materials should be removed and discarded, whereas non-porous surfaces may be cleaned. Some materials such as carpeting and drapes may be removed for professional cleaning, and the use of containment is recommended. Remediation practices further discuss the use of negative pressure in the work area and a decontamination chamber to allow for movement of equipment and contaminated debris cleaning and bagging before moving through non-affected areas. In addition, HEPA vacuuming is recommended as well as the careful use of biocides. Shaughnessy and Morey (1999) also discussed judging remediation effectiveness in which judgment includes a visual assessment that contamination has been removed and the optional use of sampling as confirmation.

The AIHA document, *Assessment, remediation and post-remediation verification of mold in buildings,* also provides recommendations for remediation work. Objectives for mold remediation work are shared with other guidance documents and include restoring building conditions, establishing conditions acceptable for the general population, and protecting worker health (Dotson et al., 2004). While relatively brief in remediation recommendations, worker protection, occupant protection, and building protection are clearly outlined. Remediation recommendations are followed with general guidelines for post-remediation verification and the use of mold testing.

The work by Bailey (2005) entitled *Fungal contamination: A manual for investigation, remediation, and control* included an overview of remediation guideline documents that included the first edition of the IICRC S520 standard. Recommendations in the text include addressing cleaning, removal, and treatment of mold contamination. Containment engineering was included as a method of controlling the unintended disbursement particulates and contaminants. Material removal was discussed and utilized the EPA handbooks on mold remediation, the New York City Department of Health guidelines, and the IICRC S520 for guidance of what may be cleaned and what should be removed. Bailey described a focus is on occupant and worker protection. Guidance documents generally agree that porous water-damaged building materials should be dried thoroughly within 24 to 48 hours, and if this cannot happen, the material should be removed and discarded. Guidance clearly states that wet gypsum wallboard and pressed board should be removed no matter how quickly it was dried. The recommendation for water-damaged gypsum wallboard is removal at least 12 in. (30.48 cm) above the indicated level of damage. Methods of cleaning were discussed including the use of wet and dry vacuuming, chemical cleaning agents, and specific methods for cleaning building materials. Disposal, cleaning of the HVAC system, personal protective equipment, and job safety area were also discussed and the use of negative air machines and air filtration devices were recommended as engineering controls. Clearance verification testing was reviewed in connection with project monitoring. First, a third-party may verify that the contractor has completed the work inside the containment area, allowing for the safe removal of the containment. Second, verification would be conducted in adjacent areas within the structure to determine if it were clean. Third, verification testing would be conducted in all the areas after reconstruction and prior to re-occupancy (Bailey, 2005). The primary difference in the Bailey (2005) description of PRV assessment and testing was that most assessments included all three steps to evaluation at the same time, rather than a progression of steps.

Public Health Concerns

Accepting that damp and moldy indoor spaces are associated with poor respiratory health is part of the theoretical framework that anchors this dissertation. The relationship between asthma and the indoor environment is commonly studied. As a disease, asthma is one of the greatest contributors to the global burden of respiratory disease and nearly four million people die prematurely from respiratory diseases each year while hundreds of millions more suffer from respiratory disease. Reducing exposure to air pollution, including indoor air pollution, is one way to avoid the development of respiratory illness and relieve the global burden. The incidence of asthma is growing exponentially across the globe, affecting more than 235 million people worldwide with an economic impact that is overwhelming (Ferkol & Schraufnagel, 2014). Globally, 180,000 deaths are attributed to asthma each year, but the greatest burden, outside of its economic impact, is in morbidity and quality of life, although the preventable risk factors include exposure to indoor environmental allergens and air pollutants (Ferkol & Schraufnagel, 2014). Asthma is a noncommunicable respiratory disease that in many cases may be preventable and it is estimated that approximately 40 million people in the United States suffer from asthma with an average cost of treating one patient annually at $3,100.00 (Nunes, Pereira, & Morais-Almeida, 2017). Mudarri and Fisk (2007) conducted a study that assessed the number of cases of asthma in U.S. homes that could be attributed to exposure to dampness and mold. Of the 21.8 million people reported to have asthma in the United States, approximately 4.6 million (21%) could be attributed to indoor dampness and mold. Through calculating the national cost of asthma in the United States annually, the authors were able to estimate that $3.5 billion is spent annually on asthma attributed to dampness and mold in the home.

The article by Mudarri (2016) entitled *Valuing the Economic costs of allergic rhinitis, acute bronchitis, and asthma from exposure to indoor dampness and mold in the US* calculated the economic burden of disease attributed to exposure to damp and moldy indoor spaces. The cost of illness and willingness to pay were reviewed, which yielded staggering statistics. For instance, in 2014, $3.7 billion was estimated for allergic rhinitis, $1.9 billion for acute bronchitis, $15.1 billion for asthma morbidity, and $1.7 billion for asthma mortality (Mudarri, 2016). From an economic standpoint, it is clear that public health policies that legislate water mitigation and mold remediation work practices could have a significant impact on asthma in the future.

Pieckova (2016) presented a common scenario in which individuals spend as much as 90% of their time indoors, with a series of potentially serious health outcomes when indoor conditions were conducive to mold growth. Wet or damp building materials may occur from condensation, excessive indoor humidity, poor ventilation, water loss, improper storage of materials, and poor housekeeping and maintenance. Without clear guidelines on prevention, remediation guidelines, and assessment, the public is left without the necessary tools to prevent exposure.

In 2011, the World Health Organization published *Environmental burden of disease associated with inadequate housing: A method guide to the quantification of health effects of selected housing risks in the WHO European region*. The documented indicated that indoor dampness and mold were associated with an increased incidence in childhood asthma, and housing conditions have become a major determinant in evaluating public health. The WHO-EUR (2011) study measured health impacts and housing risk factors in an effort to understand the environmental burden of disease, illustrating that entire populations use housing, and vulnerable segments of the populations were likely to spend more time indoors. The vulnerable portions of a population included infants, children, elderly, sick, and unemployed people and exposure to substandard housing conditions further exacerbated the risk of disease for these people. Asthma in children was the most chronic disease in childhood and therefore a major public health concern and indoor dampness and mold represented a common problem in substandard housing. Although there were no standardized methods for identifying all exposure sources, there were consistent observations for condensation, moisture and water damage, and signs of microbial growth. Given there was a lack of studies that examined specific dose and exposure quantitatively, there were numerous studies that strongly associated the presence of indoor dampness and mold to an increase in poor health outcomes for building occupants. Furthermore, increased levels of bioaerosols including spores, hyphae, and fungal fragments were associated with elevated concentrations of microbial volatile organic chemicals and damp conditions were also associated with chemical emission of some building materials.

The WHO-EUR (2011) study utilized questionnaires and inspector-reported indicators of indoor dampness and mold, whereas childhood asthma was used as the outcome for estimating the disease burden. Using population attributable fractions, the exposure-response relations and prevalence were calculated and the information on asthma was collected based on occurrence during a one-year period for six- to seven-year-old children in 15 European countries. Self-questionnaires often under-reported conditions that were noted by inspectors and inspectors were also more likely to report more severe conditions than the building occupants. In addition, WHO-EUR (2011) reviewed multiple multinational studies estimating that five percent of homes in cold climates had signs of mold problems and 15% of homes in cold climates had signs of dampness, whereas 25% of homes in warm climates had signs of mold problems and 20% of homes in warm climates had signs of dampness. Using a relative risk estimate, new-onset asthma in children and mold in the home environment were assessed, and the estimated percentage of asthma onset in children was 12% for mold exposure and 15% for exposure to indoor dampness (WHO-EUR, 2011). Further study was recommended to understand how confounding factors may affect the onset of asthma including exposure to secondhand smoke, parental atopy, pets at home, and short duration of breastfeeding, all of which are contributing factors to onset of childhood asthma. The burden on public health presented in the form of increased morbidity, use of public health services, increased absenteeism, and decreased quality of life. Exposure to dampness and mold in the home was attributed to failures in design, improper maintenance and housekeeping, construction failure, and acute incidents such as flood, plumbing failures, and storms.

Legislation

Leticia Diaz (2006) authored *The lack of mold legislation: A recipe for disaster* and at the time of the publication in 2006, nearly 30 states had enacted some type of mold legislation, although much of the legislation was related to disclosures for homebuyers and rental occupants. However, in 2016, California finally added visible mold to a list of code violations making a home or dwelling substandard with visible mold through the *California Health and Safety Code for Residential Buildings* (CAHSC, 2016). In contrast, other than public housing requirements, the federal government has done little in the way of mold legislation but after hurricane Katrina in 2005, the National Resources Defense Council reported serious threats to the residents of the area from airborne mold levels with indoor mold growth so substantial that the air outside of buildings was contaminated (Diaz, 2006). Even though the federal government has been insufficient in introducing mold legislation, few states have developed and provided work guidelines and recommendations for water damage and mold remediation (Diaz, 2006).

Menz (2015) summarized mold regulations and standards in the presentation entitled *Comparison of US Mold Regulations and Standards*. In 2003, Louisiana enacted legislation that required licenses for mold remediation contractors (LSLBC, 2003). In 2004, the Texas Administrative Code, Texas Mold Assessment and Remediation Rules (TMARR) were adopted, and an amended version of the legislation was updated in 2007, which required licensing and registration for all mold workers including technicians, consultants, companies, workers, contractors, training providers, and laboratory analysts. The TMARR (2007) set minimum work standards for both assessment and remediation and discusses sampling, the use of disinfectants, biocides, and antimicrobials, and clearance procedures, and criteria, the scope of which, may be the most comprehensive mold legislation in the country. In 2011, Florida enacted a mold related services licensing program that addresses both mold assessment and mold remediation (FL Regulations of Professions and Occupations, 2011). In 2016, the New Hampshire Senate Bill 125 went into effect, which required third-party certification for all residential mold inspections, but failed to require licensing for mold remediators (NH Occupations and Professions, 2016). In 2016, the state of New York began the process of requiring licenses for assessment consultants, mold remediation contractors, and remediation workers, eventually setting minimum work standards for mold remediation (NYS Dept. of Labor, 2016).

In Virginia, landlords are required to disclose visible mold before move-in and prospective tenants may choose to cancel the lease, although active tenants are required to keep the property in a condition not conducive to mold growth (VA § 55.1-1215, 2019). Furthermore, Virginia legislation described mold remediation in terms of performing work with "professional standards" (VA § 55.1-1215, 2019). Additionally, the state recommended the use of guidance documents published by the EPA, use of the IICRC S500 and S520, reference of the *Bioaerosols manual* published by the ACGIH, and any recommendations prepared by an industrial hygienist so long as they are consistent with the guidance documents (VA § 8.01-226.12, 2019). Compared to other states, the Virginia legislation represents an ideal example of how a state may legislate the use of guidance documents and an IEP.

As of 2020, the state of Maryland lacks any regulations related to remediation work, although some individual counties enacted laws that required property owners maintain rental spaces free from water damage and mold (MCDEP, 2017). Montgomery County enacted mold legislation that related to the responsibility of the landlord to "locate and correct underlying cause," which referenced following the EPA maintenance guidelines related to mold (MCDEP, 2017, p. 5).

In 2017, New Jersey published mold guidelines for residents that contained sections on understanding mold, health concerns, hiring a consultant or remediation contractor, and recommendations on who should clean up mold, but unfortunately, some resource links in the document were broken and unattainable on the website (MCDEP, 2017). Although the state was successful in publishing mold guidelines for residents, the requirements for consultant licensing and qualified remediation contractors were ambiguous and vague.

Of the entirety of mold legislation in United States in 2020, the California Department of Public Health (CDPH) made one of the strongest statements about the association between indoor dampness and mold and increased health risks. Simultaneously, the CDPH recommended against environmental sampling as part of the assessment for determining mold contamination:

> CDPH has concluded that the presence of water damage, dampness, visible mold, or mold odor in schools, workplaces, residences, and other indoor environments is unhealthy. We recommend against measuring indoor microorganisms or using the presence of specific microorganisms to determine the level of health hazard or the need for urgent remediation. Rather, we strongly recommend addressing water damage, dampness, visible mold, and mold odor by (a) identification and correction of the source of water that may allow microbial growth or contribute to other problems, (b) the rapid drying or removal of damp materials, and (c) the cleaning or removal of mold and moldy materials, as rapidly and safely as possible, to protect the health and well-being of building occupants, especially children. (CDPH, 2016, p. 1).

Theoretical Orientation and Conceptual Framework

Two widely accepted theories were chosen to form the theoretical foundation of this dissertation research: (a) damp and moldy indoor environments are positively associated with an increased risk of poor health outcomes for building occupants (Carter et al., 1883; CDPH, 2016; Diaz, 2006; Fisk, Lei-Gomez, & Mendell, 2007; IOM, 2004; Kennedy & Grimes, 2013; WHO-EUR, 2009) and (b) and disturbing damp and moldy building materials equate to an increase in microbial activity indoors (IOM, 2004; Johanning et al., 2014; NASEM, 2016; NASEM, 2017; WHO-EUR, 2009). There are also two consensus documents that are commonly used to guide water damage mitigation and mold remediation practices (IICRC, 2015a; IICRC, 2015b). While not required by law in California, several other states recommend following work procedures in these consensus documents in an effort to: (a) protect worker health, (b) protect occupant health, and (c) return the work area to a pre-loss condition. The consensus documents recommend the involvement of an IEP for assessment and post-remediation verification and clearance testing (IICRC, 2015b). When a project is presumed to be successfully remediated, the IEP verifies the completion of the work through an assessment and testing for airborne mold spores. As such, the dissertation research aims to determine if following the recommended work practices in consensus documents will, more frequently, result in a successful remediation project. The success of a remediation project is quantified by an IEP report and third-party laboratory analysis of air samples collected by the IEP. Health and safety aspects were considered beyond the scope of the dissertation study, therefore, the research focused on the use of two specific consensus documents, the *ANSI/IICRC S500 Standard and reference guide for professional water damage restoration – fourth edition: 2015* [S500] and the *ANSI/IICRC S520 Standard for professional* *mold remediation – third edition: 2015* [S520]. The theoretical orientation related to the consensus documents is depicted in Figure 1.

After the discovery of a presumed condition of dampness or mold in a home, water damage mitigation or mold remediation activities may commence. The condition of the affected area, prior to the loss, is referred to as the pre-loss condition, and the pre-loss condition is largely undocumented. In addition, the cause of dampness or mold may be known or unknown and the entity responsible for returning the affected area to the pre-loss condition is responsible for choosing and implementing work practices, whereas the implemented practices may or may not follow the recommended guidelines found in the consensus documents (S500 and S520). Following completion of the work, an IEP may be retained to evaluate the success of the project, and the IEP evaluation includes an assessment of the affected area or areas and air sampling. Further, the IEP provides a written report that concludes the completion of the project along with third-party laboratory analysis of spore trap air samples for mold spores. The conceptual framework for this study is shown in Figure 2, which illustrates is the related nature of the dependent and independent variables.

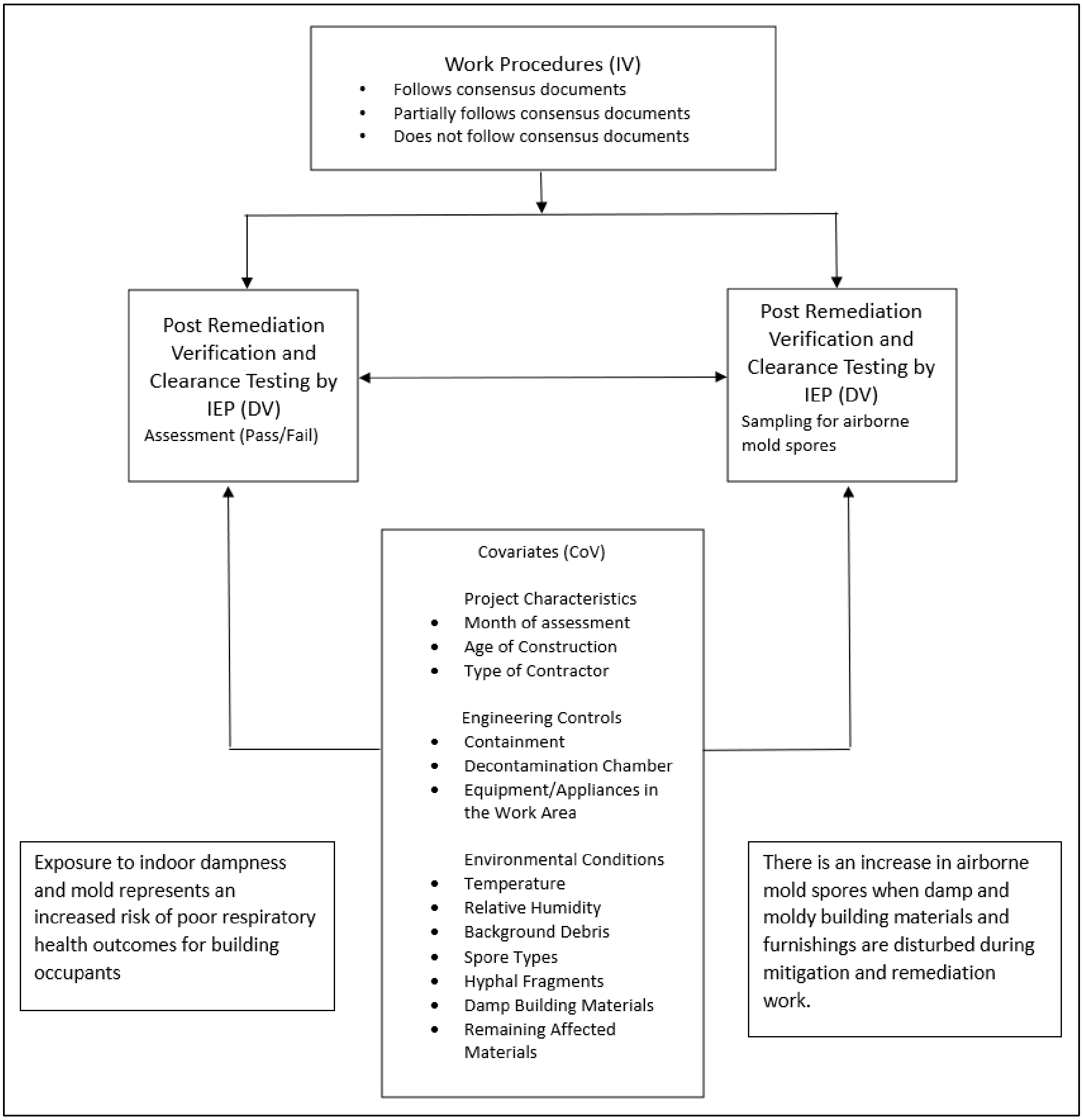

Figure 1. Theoretical orientation.

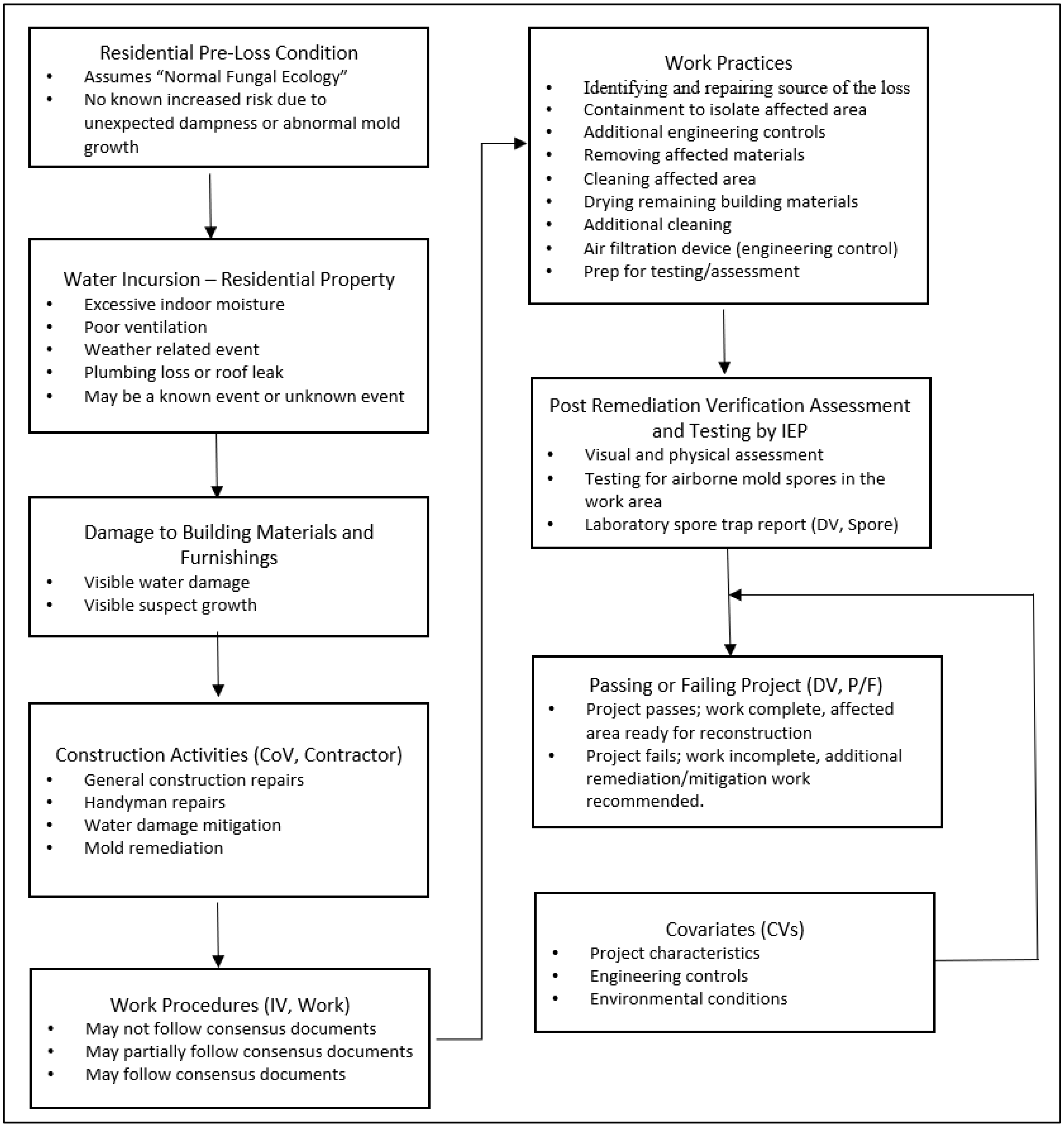

Figure 2. Conceptual framework for the remediation work process.

Hypotheses

H_{01}. There is no association between the airborne mold spore count in the work area and the pass-fail assessment of the IEP.

H_{a1}. There is an association between the airborne mold spore count in the work area and the pass-fail assessment of the IEP.

H_{02}. There is no association between the airborne spore count in the work area and how the work is performed.

H_{a2}. There is an association between the airborne spore count in the work area and how the work is performed.

H_{03}. There is no association between the pass-fail assessment of the IEP and how the work is performed.

H_{a3}. There is an association between the pass-fail assessment of the IEP and how the work is performed.

Summary

Although health outcomes were excluded from this study, the literature review documented the widely accepted theories of the theoretical framework of this dissertation research: (a) exposure to damp and moldy indoor spaces increases the risk of poor health outcomes and (b) disturbing damp and moldy building materials may increase the risk of exposure for building occupants. Several associations between disturbing damp and moldy building materials and aerosolizing bioaerosols including mold spores were identified and described. Sampling methodologies for determining the level of mold were discussed and exposure limits for airborne mold spores in residential environments were explored. Two consensus documents were detailed, which provide recommendations for water damage and mold mitigation practices to individuals performing this type of work. The impact to public health was documented and shown to impact morbidity and economic burden in various countries and regions of the United States. Although legislation recommending best work practices in California was found to be nonexistent, the California Department of Public Health acknowledged that exposure to damp and moldy indoor spaces is unhealthy. The information included in IEP reports and laboratory analyses were chosen as the data source to examine the relationship between how work is performed and the outcome of the remediation projects, whereas the presumed variable relationships in the remediation work process were discussed and organized into the conceptual framework guiding this dissertation study.

Chapter III: Methodology

Using existing data from post-remediation verification and clearance testing reports, this study explored the relationship between how mold remediation work was performed, the resulting total airborne mold spore counts in the work area, and IEP final assessment reports. Rather than looking to identify a cause-and-effect relationship between the work and the results of the PRV, this study first examined the correlation of existing data with the project outcome. By uncovering an association between how the work was performed and the project outcome, the use of consensus guidance documents on water mitigation and mold remediation were considered valuable in eliminating damp and moldy indoor conditions in residential structures following water loss. The elimination of damp and moldy indoor conditions presumes a reduced risk of poor health outcomes for building occupants. Using data from existing residential PRV reports, a database of variables was created to allow for the statistical analyses.

The dissertation research study explored the association between how water damage and mold remediation work is performed and the outcome of the project as evaluated by the IEP and the total spore count in the work area. The research used project data from IEP reports following mold assessments and post-remediation verification and clearance testing and laboratory analyses reports. The individual projects (n = 267) were completed in residential properties in southern California within the past 10 years. The geographic boundary was selected to include projects in a similar climate region, thus eliminating weather events that occur in other areas of the country and to maintain similar environmental conditions (e.g., temperature, relative humidity). The climate region was defined by the Köppen-Geiger climate zones and included the following counties in southern California: San Diego, Orange, Los Angeles, Riverside, San Bernardino, and Imperial (Beck et al., 2018). The included projects were limited to water damage and mold assessments with post-remediation verification and clearance testing that included air sampling. Only residential buildings were included in the study and the projects were also limited to those with data available in physical or digital format: job number, date of assessment, project address, IEP report, and third-party laboratory report containing spore counts. The data were input into a spreadsheet that was imported into the statistical software, and a unique number was assigned to each project as an identifier.

Research Design

A quantitative, nonexperimental correlational design using secondary data was selected to execute the retrospective dissertation research study. As nonexperimental research, there was no manipulation of independent variables and the study was not designed to examine causation but rather relationships between variables. The objective of this research was to identify and measure the strength of the associations among the variables. Primary data was collected in the form of a survey, report, and secondary data in the form of laboratory reports, job notes, and photographs. The research design limits the ability to generalize the results to all water damage or mold projects.

The airborne mold spore counts in the work area, project characteristics, environmental characteristics and conditions, presence and use of engineering controls, pass or fail of the IEP reports were quantitative data. In addition, the assignment of contractor type and how work followed consensus documents were also included. A number of additional quantitative factors were included in IEP reports, including the decision to pass or fail a project that was subjective and at the discretion of the IEP. Because there is no law or rule that governs passing criteria for a project, each IEP was responsible to interpret the results of testing and assessment and it was possible that two projects with the exact number of airborne mold spores in the work area would not receive the same IEP pass or fail. A sample IEP report, chain of custody example, and project data questionnaire are included in Appendix A, Appendix B, and Appendix C, respectively.

Population and Sample

A broad evaluation of potential sample population size from five distinct IEPs yielded a total of (n = 850) projects with PRV reports. Projects were eliminated from the sample population pool if inclusion criteria were not met and the inclusion criteria of qualified projects required that each project contain certain data and specific characteristics:

1. Residential property in southern California (i.e., the counties Los Angeles, San Diego, Orange, Riverside, Imperial, and San Bernardino).
2. Experienced a loss that resulted in water damage mitigation or mold remediation.
3. A post-remediation verification report was created.
4. Airborne testing for mold spores in a work area were included in the report with a complete laboratory report and chain of custody.
5. Job notes or photographs of the work accompanied the reports for verification of data contained in the report and to assist in the code of “work.”
6. The project must have been completed and assessed after between 2008 and 2019.

Sample size and power analysis. A power and sample size analysis was conducted a priori to study execution that considered a sample population of (N = 850) with a minimum power value set at ($1 - \beta = 0.80$) to detect an effect size (OR = 0.10) less or greater than the null (OR = 1.00), and a type I error rate set at ($\alpha = 0.05$), which yielded a minimum sample size of (n = 265). The total sample size of this study was (n = 267), which contained 231 reports representing one IEP and 36 reports aligning to four additional IEPs that did not represent a percentage of a known population. The work of IEPs is considered proprietary and protects client and contractor identities, which hampers IEP-related data collection. Although some contractors were forthcoming with reports and supplied a number of projects to the sample population, there was no centralized database; hence, manual data collection and dataset creation were required.

Materials and Instrumentation

The consensus documents, the *ANSI/IICRC S500 Standard and reference guide for professional water damage restoration – fourth edition: 2015 [S500]* and the *ANSI/IICRC S520 Standard for professional mold remediation – third edition: 2015 [S520]*, were used to guide the research. The S500 provides guidance on water mitigation work including evaluation, assessment, and work practices to mitigate the damage and restore water-damaged structures and was written for those involved in the water damage restoration industry, primarily restoration companies and workers (IICRC, 2015a). Secondarily, the document provides a resource for those investigating and assessing water incursion events that discusses the principles of water damage restoration, building and material science, psychometry, and health and safety for workers and building occupants. In contrast, the S520 provides guidance on mold remediation work, including defined criteria and methods to be used for inspecting and investigating abnormal moisture and mold contamination (IICRC, 2015b). The standard also provides recommendations for work practices including cleaning, training, and engineering controls, the latter of which utilize methods, equipment, and containments to minimize and limit exposure to damp and molding conditions for workers and building occupants. Air filtration devices and containments are two primary methods for controlling exposure in addition to the use of personal protective equipment (PPE) for workers. Because project monitoring was not part of this retrospective study, cleaning methods and the use of PPE could not be used to determine how the work was completed. However, the presence of specific engineering controls like containment and air filtration devices were used to determine how the work was completed. The consensus documents also defined and described the use of an IEP, an individual who is qualified to perform an assessment of a damp or moldy condition that confirms proper fungal ecology following water damage mitigation and mold remediation work (IICRC, 2015b).

Secondary data was collected from post-remediation verification and clearance testing reports and surveys. Initially, a survey included in Appendix C was sent to multiple IEPs and contractors and the recipient was invited to complete and return the survey for possible inclusion in the study. The data from each survey was input into a spreadsheet to create a dataset for the analysis. Given that errors may occur when completing surveys and during data entry, it was determined that the actual report and accompanying documentation (i.e., laboratory report, chain of custody, job notes, and photographs) would be sent electronically. Using the reports and accompanying documentation, the necessary data were collected and input directly into the dataset, thus eliminating one step and potentially reducing errors.

While each contractor may be a licensed general contractor according to the California Contractor State Licensing Board, each contractor type was coded numerically according to the general type of work performed (CA Business and Pressions Code, 2005). Each contractor company specializing in mitigation and remediation work was coded as a (1 = remediator). For example, a certain company may be a general contractor, but if the company specializes in mitigation and remediation, the contractor was coded at one level of the nominal variable 'contractor.' The other contractors who work independently were coded as (2 = general contractor) even if the specialty work is only kitchens or baths. For instance, kitchen and bath specialists were coded as a general contractor because of the lack of specialization in mitigation or remediation. Each worker employed by a property management company or property manager and did not work independently was coded as (3 = handyman). Each contractor was assigned a unique numerical identifier in the dataset, although the identifier was not used for research and only the type of contractor was included in the analyses.

The variable ‘work’ was defined by how closely the work followed general recommendations contained in the consensus documents. The ordinal work variable was coded into three categories: (a) does not follow consensus documents (1 = no), (b) partially follows consensus documents (2 = partial), and (c) follows consensus documents (3 = yes). In the event that work according to consensus documents was not specified by an IEP, work adherence to consensus was assigned through an objective assessment of the data contained in the job notes, IEP report, and photographs to assign the work to one of three levels of the variable. For example, if the contractor employed the use of containment (with or without decontamination chamber) and air filtration devices, the work was coded following the consensus documents (3 = yes), whereas if the contractor used a containment but did not use an air filtration device, the work was coded partially following the consensus documents (2 = partial), or if the contractor used an air filtration device but did not use a containment, the work was also coded as partially following consensus documents (2 = partial). However, if the contractor did not employ a containment or an air filtration device, the work was coded as not following consensus documents (1 = no). In addition, in the PRV reports, some IEPs noted the presence of containment and appliances in the work area, which was annotated from the report to code work adherence to the appropriate level, whereas if no information was contained in the report, the job notes and photographs of remediation projects were reviewed for information to confirm the presence or lack of containment and appliances allowing work adherence coding for the correct level. Given that the necessary information to code work adherence for a project was not available, the project was excluded from the dataset.

An IEP conclusion of pass or fail represented a nominal dichotomous variable, 'pass-fail,' that was coded as pass (1 = pass) or fail (2 = fail). The terms "pass" and "fail" are not generally used, rather common phases are often used in place of the two words. For instance, a "pass" phrases are often termed as "remediation work is complete and the affected area is ready for reconstruction" or "no further mitigation is warranted." In contrast, examples of "fail" phrases are frequently termed as "remaining affected building materials were noted," "please remedy and contact the IEP for follow-up assessment," or "the affected area is not ready for reconstruction." Regardless of the variation in phrasing remediation projects passing or failing, the information contained in IEP reports was extracted and categorized, and each IEP and laboratory were assigned separately unique numerical identifiers in the dataset. When there was no indication in the IEP reports that the remediation work was completed or satisfactory, then the project was excluded from the dataset.

The presence of the containment (1 = yes; 2 = no) was used to determine how the work was completed that was graded in assessment by an IEP. In PRV reports, the containment condition was noted, and the 'condition' represented four levels of grading and was used in this study as an ordinal variable with four levels coded as good (1 = good), fair (2 = fair), poor (3 = poor), or not present (4 = none). When the condition of the containment was not noted in the PRV reports, then the job notes and photos were assessed to determine the condition of the containment. Given the containment was present without breaches, it was coded as (1 = good), when the containment was present and had a minor tear, the containment was coded (2 = fair), if the containment was present and falling down or had multiple breaches, it was coded poor (3 = poor), and when containment was not present, it was coded (4 = none).

The presence of the decontamination chamber, a nominal dichotomous variable coded as (1 = yes; 2 = no) was established by the information collected from the PRV reports. In the event that the PRV reports failed to document the presence of a decontamination chamber, the job notes and photographs were used to determine the presence of the decontamination chamber. In addition, equipment and appliances present during an assessment were graded at three levels: (a) air filtration device (AFD), (b) air scrubber, or (c) dehumidifier. A nominal variable with three levels, 'equipment' was coded according to the type of equipment as (1 = AFD) for air filtration device, (2 = air) for air scrubber, and (3 = dehumidifier) for dehumidifier. Given instances that equipment was not noted in the IEP report or job notes, the job photographs were used to determine whether equipment was present and the type of equipment.

Information on the chain-of-custody (Appendix B) and laboratory reports (Appendix A) were extracted, the values were entered into the dataset, fields were left blank if data were missing. The data on total spores in work areas, total spores in other non-work areas, total spores outside, background debris score, and hyphal fragment count were extracted from laboratory reports, whereas data on the temperature in the work area, relative humidity in work area, and month of assessment were extracted from PRV reports or Chain of Custody documents when the information was noted. The presence of mold type *Stachybotrys* was extracted from laboratory reports and coded as a nominal dichotomous variable (1 = yes; 2 = no), whereas data on affected 'materials,' 'damp' materials, and 'retest' were extracted from PRV reports when possible and coded as nominal dichotomous variables (1 = yes; 2 = no). The age of the structure was documented based on assessment of the project address through online public records searches.

Variables and Operational Definitions

Three research questions guided this dissertation study to examine the associations among mold spore count, pass-fail assessments of mold remediation projects, and how closely mold remediation work followed consensus documents.

RQ1. Is there an association between the airborne mold spore count in the work area and the pass-fail assessment of the IEP?

RQ2. Is there an association between the airborne spore count in the work area and how closely the work follows consensus document guidelines?

RQ3. Is there an association between the pass-fail assessment of the IEP and how closely the work follows consensus document guidelines?

Independent variable. The independent variables were the factors that influence the outcome of the project. There is one primary independent variable, 'work.' The work either 1) did not follow recommendations in one of the two primary consensus documents, 2) partially followed recommendations in one of the two primary consensus documents, or 3) did follow the consensus document recommendations when performing the work. The consensus documents were identified as *ANSI/IICRC S500 Standard and reference guide for professional water damage restoration – fourth edition: 2015* [S500] and the *ANSI/IICRC S520 Standard for professional mold remediation – third edition: 2015* [S520]. When information was not documented by the IEP, data from contractor, job notes, or photographs was used to code the variable appropriately. The 'work' variable was measured on an ordinal discrete scale and was not determined by 'contractor' type (Table 1).

Dependent variables. There were two primary dependent variables in this study and the first dependent, or outcome variable was total airborne mold spore count in the work area ‘spore,’ the data for which were provided on third-party laboratory reports and in some IEP reports. The ‘spore’ variable was measured on a ratio scale ratio instead of interval since zero has meaning. In addition, the second dependent variable was the ‘pass-fail’ assessment of projects by IEPs measured on discrete, nominal dichotomous scale and coded at two levels based on the conclusion drawn in IEP final reports. The pass-fail of the project was at the sole discretion of the IEP and could include several influential factors such as ‘spore,’ presence of affected or damp materials, and cleanliness (Table 1).

Table 1

Summary of Independent and Dependent Variables

RQ	Variable	Type	LoM	Values	Data source
RQ1	Spore	IV1	Ratio	0, 1, 2,..., *n*	Lab reports IEP reports
RQ1	Pass-fail	DV1	Nominal	1 = pass 2 = fail	IEP reports
RQ2	Work	IV2	Ordinal	1 = no 2 = partial 3 = yes	IEP reports Notes Photographs
RQ2	Spore	DV2	Ratio	0, 1, 2,..., *n*	Lab reports IEP reports
RQ3	Work	IV3	Ordinal	1 = no 2 = partial 3 = yes	IEP reports Notes Photographs
RQ3	Pass-fail	DV3	Nominal	1 = pass 2 = fail	IEP reports

Note.

In addition to the primary research questions, several sub-questions will address covariates based on PRV reports that were organized into three categories: (a) project characteristics, (b) engineering controls, and (c) environmental conditions. The effect of the covariates on the dependent variables was explored and measured through correlational analyses.

Covariates. The covariates of this study are shown in Table 2 and Table 3, which represent the variables that had the potential confound or modify the effects of 'spore count', 'pass-fail' assessment, and 'work' adherence to consensus documents

Month. Month of assessment represents the date by 'month' that samples were collected, which was recorded in the Chain-of-Custody documents and IEP reports and measured on a nominal, discrete scale.

Temperature. Temperature is one of a few factors that influence fungi survival and growth and here, temperature of the affected area refers to the ambient temperature in degree Fahrenheit pertaining to the time of sampling that was recorded on IEP reports, job notes, or the Chain-of-Custody (Burge & Otten, 1999). The 'temperature' variable was measured on a continuous interval scale (i.e., the Fahrenheit scale does not have an absolute or meaningful zero).

Humidity. Humidity and moisture are also factors that influence fungi survival and growth and relative humidity refers to the percentage humidity of the affected area noted at the time of sampling, which may be recorded on the IEP reports, in job notes, or on the Chain-of-Custody documents (Burge & Otten, 1999). The 'humidity' variable was measured on a continuous ratio scale.

Age. For this study, age refers to the age of the structures involved in remediation projects that was noted in IEP reports, or job notes as a completion date by year was noted or sourced from public records via address searches with the information was not available. The variable 'age' was measured on a ratio scale since there is a meaningful zero at the initiation of construction up to completion and the age of construction can be measured in discrete units (years).

Contractor. A contractor in this study refers to the type of contractor: A remediator, general contractor, or handyman-maintenance worker noted in IEP reports. The variable 'contractor' was measured on a nominal scale at three levels (1 = remediator; 2 = general contractor; 3 = handyman) and only contractor type was assessed in this study.

Containment. Containment refers to consensus-recommended containment barriers that separate affected work areas from other areas (IICRC, 2015b). Information on the presence and condition of a containment was noted in IEP report, job notes, and photographs. The condition of 'containment' variable was measured on an ordinal scale with four levels: good (1 = good), fair (2 = fair), poor (3 = poor), or not present (4 = none).

Decontamination. Decontamination in this study refers to decontamination chambers that are isolated spaces between the containment (affected area) and adjacent non-affected spaces, which are recommended to be set up to act as neutral workspaces (IICRC, 2015b). Information on the presence of decontamination chambers was noted in IEP reports, job notes, and photographs. The 'decontamination' variable was measured on a nominal dichotomous scale to serve as an indicator of the presence of decontamination chambers.

Equipment. Equipment refers to any equipment or appliances involving air filtration in the work area and information regarding the presence of equipment were included in IEP reports, job notes, or photographs. The 'equipment' variable was measured on a nominal scale at three levels: air filtration device (1 = AFD), air filtration device and dehumidifier (2 = AFD + dehumidifier), no equipment (3 = no equipment), and dehumidifier (4 = dehumidifier).

Non-affected area spore (NAA-spore) count. The non-affected area spore count refers to the raw spore count in the unaffected area, presumably in the same building and near the affected area, documented on IEP reports although some IEPs do not collect air samples. The 'NAA-spore' variable was measured on a ratio scale.

Outside spore (outside-spore) count. The outside spore count refers to the spore count outside an affected structure documented on IEP reports, and when more than one outside sample is collected, only the sample collected in the front of the residence is noted. The 'outside-spore' variable was measured on a ratio scale.

Debris. Debris refers to a third-party laboratory analyst estimations of the amount of background debris in an air sample recorded on laboratory reports. The recorded number for background debris is representative of the non-biological particles (dust) noted in the sample, and excessive dust can result in reduced visibility for the analyst, but it also may indicate a dirtier environment. The variable 'debris' was measured on an ordinal scale at eight levels: (1 = 1, 2 = 1+, 3 = 2, 4 = 2+, 5 = 3, 6 = 3+, 7 = 4, 8 = 4+ low), which aligned to the unique scale of the laboratory analyst: (1, 1+, 2, 2+, 3, 3+, 4, 4+).

Spore type Stachybotrys (mold-stachy). Third-party laboratory reports recorded spore type identification in addition to enumeration. The presence of Stachybotrys, represented by 'mold-stachy' is a nominal dichotomous indicator variable coded as (1 = yes; 2 = no) without regard for the number of spores.

Hyphal fragments (Hyphae). Hyphae are fragments of mold growth representative of the vegetative and reproductive structures that together form the mycelium of a fungus (Burge & Otten, 1999). Third-party laboratory analysts may calculate the number of hyphal fragments identified on the air sample, and the number was recorded on the laboratory reports. The variable 'hyphae' is a ratio variable that represents for number of hyphal fragments.

Affected materials in the work area (affect-mat). Affected materials that remain in the work area (i.e., water stained carpet tack strip or visible suspect growth) may cause elevated spore counts in the work area and can be a cause for a failing report by an IEP. The information regarding affected materials was noted by the IEP during the visual assessment part of PRV and information may also be included in the IEP report, job notes, or photographs. The 'affect-mat' variable is a nominal dichotomous indicator variable coded as (1 = yes; 2 = no) representing the presence of affected materials.

Damp building materials in the work area (damp-mat). Damp materials in the work area may promote fungi growth and cause elevated spore counts in the work area. As a result, damp building materials may be a cause for a failing report by the IEP. The information on the presence of damp materials was noted by the IEP during the assessment part of PRV and may be included in the IEP report, job notes, or photographs. The presence of damp materials represented by 'damp-mat,' is a nominal dichotomous indicator variable coded as (1 = yes; 2 = no) showing whether damp materials were present.

IEP. There are no specific standards for mold exposure in PELs and the IEP reports are subjective. Each IEP may have different sampling techniques, assessment strategies, calibration and decontamination procedures, sampling pumps, and sampling media. To indicate specific IEPs, each independent environmental professional was assigned a unique identifier represented by the nominal 'IEP' variable.

Retest. A retest is a project that was previously tested, received a fail grade by an IEP, and was in the process of a reassessment. The results of subsequent testing at a later date, were presumed to have corrected deficiencies identified during the original assessment and testing.

The ‘retest’ variable was measured on a nominal dichotomous scale and coded as (1 = yes; 2 = no) to indicate that a project was retested.

Table 2

Summary of Covariates

Variable	Type	LoM	Values	Data source
Month	CoV1	Nominal	1, 2, 3,..., 12	COC report IEP report
Temperature	CoV2	Interval	1.0, 2.0,..., *n*	IEP report Notes COC report
Humidity	CoV3	Ratio	0.0, 1.0,..., *n*	IEP report Notes COC report
Age	CoV4	Ratio	0, 1, 2,..., *n*	IEP report Notes Public records
Contractor	CoV5	Ordinal	1 = remediator 2 = general contractor 3 = handyman	IEP report
Containment	CoV6	Nominal	1 = yes 2 = no	IEP report Photos, notes
Condition	CoV7	Ordinal	1 = good 2 = fair 3 = poor 4 = none	IEP report Photos, notes

Table 3

Summary of Covariates

Variable	Type	LoM	Values	Data source
Decontamination	CoV8	Nominal	1 = yes	IEP report
			2 = no	Photos, notes
Equipment	CoV9	Nominal	1 = AFD	IEP report
			2 = AFD + dehumidifier	Photos, notes
			3 = no equipment	
			4 = dehumidifier	
NAA-spore	CoV10	Ratio	0, 1, 2,..., *n*	IEP reports
Outside-spore	CoV11	Ratio	0, 1, 2,..., *n*	IEP reports
Debris	CoV12	Ordinal	1 = 1, 2 = 1+	Lab reports
			3 = 2, 4 = 2+	
			5 = 3, 6 = 3+	
			7 = 4, 8 = 4+	
Mold-stachy	CoV13	Nominal	1 = yes	Lab reports
			2 = no	
Hyphae	CoV14	Ratio	0.0, 1.0,..., *n*	Lab reports
Affect-mat	CoV15	Nominal	1 = yes	IEP reports
			2 = no	Photos, notes
Damp-mat	CoV16	Nominal	1 = yes	IEP reports
			2 = no	Photos, notes
IEP	CoV17	Nominal	0, 1, 2,..., *n*	Created
Retest	CoV18	Nominal	1 = yes	IEP reports
			2 = no	

Data Collection and Statistical Analysis

A single research hypothesis, that there was a significant correlation between how remediation work was performed and the final project outcome as defined by the total airborne mold spore count in the work area and the final assessment by an IEP, guided and supported the three main statistical hypotheses statistically tested in this study:

$\mathbf{H_{01}}$. There is no association between the airborne mold spore count in the work area and the pass-fail assessment of the IEP.

$\mathbf{H_{a1}}$. There is an association between the airborne mold spore count in the work area and the pass-fail assessment of the IEP.

$\mathbf{H_{02}}$. There is no association between the airborne spore count in the work area and how the work is performed.

$\mathbf{H_{a2}}$. There is an association between the airborne spore count in the work area and how the work is performed.

$\mathbf{H_{03}}$. There is no association between the pass-fail assessment of the IEP and how the work is performed.

$\mathbf{H_{a3}}$. There is an association between the pass-fail assessment of the IEP and how the work is performed.

The data collection of the study occurred in the form of surveys and IEP reports with supporting job notes, job photographs, and laboratory reports. Five IEPs were contacted to request data for the research although IEPs were reluctant to complete the surveys. The process of filling out the surveys and then inputting the survey data was more cumbersome than extracting data directly from the PRV and associated documents. Therefore, the solution was to collect original PRV, associated documents, and files electronically, which were provided by

IEPs and contractors. The original PRV, associated documents, and files were maintained in electronic formats such as Microsoft Word documents, Microsoft Excel spreadsheets, image (IMG) files, and portable document files (PDFs) as backed up on an external drive. Once the data were extracted from electronic PRV reports, laboratory reports, job notes, and photographs, the data were input into Excel spreadsheets. The data were then cleaned, and each variable was coded to the proper level of measurement before the spreadsheet was imported into Intellectus Statistics™ for the analyses.

The study first examined and estimated descriptive statistics before conducting bivariate and multivariate analyses, the latter two of which were used to assess associations and the strength of the associations between the study variables. Descriptive statistics were calculated to describe the existing data for each of the study variables by producing tables containing measures of frequency, percentage, means, median, variation, standard deviations, 95% confidence intervals, skewness, standard errors, and range. A significance threshold ($\alpha = 0.05$) was established for null hypothesis significance testing for each of the hypotheses in this study.

The bivariate tests included the Mann-Whitney *U* test, chi-square test of independence, and Fisher's exact test, whereas the multivariate tests were the Kruskal-Wallis test and binary logistic regression, all of which were used to determine associations and the strength of the associations between the independent variables, dependent variables, and covariates. Skewness and kurtosis for several variables indicated a non-normal distribution of data, which was problematic given the violation of assumptions and conditions (Figure 3). Therefore, the two-tailed Mann-Whitney *U* test was selected as a non-parametric alternative to the independent samples *t*-test because of the non-normal distribution in the dependent variable (spore) and, as a two-sample rank sum test, the Mann-Whitney *U* test assumptions were not the same and more favorable given the data distribution. A Kruskal-Wallis rank sum test was also selected as a non-parametric alternative given the data distribution assumptions of the one-way ANOVA would be violated.

Table 4

Summary of Bivariate Analyses

RQ#	IV (LoM)	DV (LoM)	Statistical test
RQ1	IV1 (ratio)	DV1 (nominal)	Mann-Whitney U test
RQ3	IV3 (nominal)	DV3 (ordinal)	Chi-square test of independence

Note. RQ = research question, LoM = level of measurement, DV = dependent variable, IV = independent variable.

Table 5

Summary of Multivariate Analyses

RQ#	IV + CoVs	DVs	Statistical test
RQ2	IV2+ CoV1-COV3	DV2	Kruskal-Wallis rank sum test
RQ4*	IV3 + CoV5 + CoV6	DV1-DV3	Logistic regression

Note. RQ = research question, CoVs = covariates, DV = dependent variable, IV = independent variable, * = a posteriori research question.

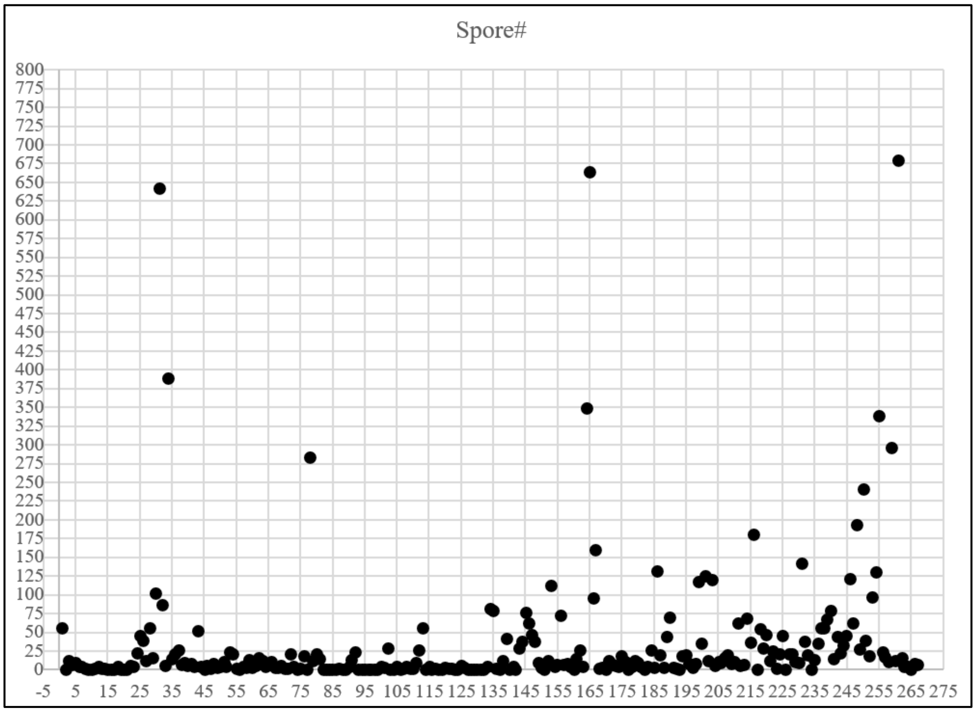

Figure 3. An example of skewed, non-normal distribution for spore.

Assumptions

The focus of this research was the relationship between consensus document recommended work practices, IEP assessments, and airborne mold spores in the work area following water damage restoration and mold remediation activities. Coding for the 'work' variable was subjective, and it was assumed that projects with containment and air filtration devices in place followed consensus recommended guidelines and projects with either a containment or air filtration device in place were partially following consensus document guidelines. It is also assumed that a project that has neither containment nor an air filtration device did not follow the consensus document guidelines. When coding the 'contractor' variable, it was assumed that a contractor that did not self-identify as a remediation or mitigation contractor was a general contractor regardless of other specialty. In addition, the condition of the containment was assumed to align with the evidence supporting remediation projects, not the actual presence of containment, although some projects included specific notation on the quality of the containment that was present. Since a target population of PRV projects data does not theoretically exist with regard to formally collected and centralized data, there is no practical way to ascertain whether the study population examined in this study was representative of all PRV projects. The relationships and correlations identified in the analysis are representative of only the projects assessed in this study, and the study results cannot be assumed to possess external validity or generalizability to other projects in the areas targeted for this study or in other geographic locations.

Limitations

The dissertation research was aimed at determining the effectiveness of mold remediation protocols in reducing airborne mold spores following water damage restoration and mold remediation activities. It was assumed that by following consensus document recommended work practices including follow up testing and assessment by an IEP, the risk of exposure to damp and moldy conditions for building occupants would be reduced. Therefore, the assumed reduction in risk implied a healthier environment. In addition, the study was designed to answer questions about the relationship between work practices and the success of the project as evaluated by IEP reports and air testing for mold and each building included in the study may have very different characteristics including the nature of the loss, building characteristics, function space use, furnishings, and environmental conditions. Furthermore, the results of the study were time bound and may not relate to a sequence of events or give insight into historical events, and consequently the study results cannot be used to establish cause-and-effect relationships. Although there is a possibility that the study may have different results if a different snapshot in time was selected, there were no follow-up findings for the study and the results may not be extrapolated to all mold remediation projects. However, the study results provided a foundation for additional case studies and research, will stand for the specific period under study, and may not be applicable to any other time or circumstance whether different, similar, or even exact.

The sampling methodology was based on reports completed by IEPs like the report shown in Appendix A, and the IEP represented the person who completed the post-remediation verification assessment and clearance testing. As such, there was potential for bias such as the bias found in survey instruments, and several limitations arising from the use of surveys to collect data. The survey of this study included data related to each water mitigation or mold remediation project, which would be most accurate when a single individual recorded the data and there were no additional errors when completing the survey. If the quality of the data recorded was questionable, the data could be flawed. For instance, each of the IEP reports contained a spore trap report from a third-party laboratory and an accompanying chain-of-custody document and one of the dependent variables was the raw 'spore' count, whereas the other dependent variable was the 'pass-fail' report by the IEP. Because the pass-fail report represents a discretionary decision by the IEP, bias could be introduced since each IEP has unique criteria for passing or failing a project, and a IEP may employ different criteria for different jobs.

Several confounding variables may have contributed to the pass-fail. For example, the spore count in the work area was acceptable but the remaining building materials had elevated moisture content (damp), the project would fail in the assessment. Many of the potential confounding variables were recorded on the laboratory reports and accompanying chain-of-custody documents. Another potential confounding variable was 'containment' and the consensus documents called for the containment to be constructed around the affected area before the affected materials were disturbed, although in the field, materials are sometimes removed and then the containment is constructed around the affected area. One common reason for this occurrence is the presence of large appliances or bulky building materials that need to be removed and the containment openings that are often made from flaps or zippers in polyethylene sheeting which do not easily allow for passing through large materials. Sometimes workers remove large objects and then build a containment, but the IEP lacks the knowledge of when the containment was erected but should note if there was an existing containment around the affected area. Therefore, it is possible that the process influenced the outcome of airborne mold spore testing.

An addition potential limitation was contractor work practices since some contractors self-identify as following consensus documents, although without project monitoring, it is not possible to know if the consensus recommendations were followed. The consensus documents only recommend work practices and the onus rests with the individual performing the work as to how closely the recommendations were implemented. Each IEP must make a judgment call on whether it is believed that the consensus documents were followed based on visual assessment and review of the PRV and accompanying documents and files. Since the IEP is responsible for recording conditions at the time of testing and assessment, inaccurate or inadequate record-keeping may have resulted in mold sampling errors and other errors that introduced bias into the data. While it is widely accepted that damp and moldy indoor environments equate to an increased risk of poor health outcomes for some building occupants, there is no known threshold of acceptable limits for airborne mold spores. Therefore, it was assumed that fewer mold spores equated to a reduced health risk, although health outcomes were not assessed in this study.

Another potential limitation and also a delimitation was the type of construction for the projects. For the study, only residential projects were included and by restricting the type of construction, similar framing and building materials were assumed to be used in the projects. By restricting to residential projects, the results of the study were limited in generalizability and scope. In addition, the age of construction is another limitation since materials have changed over the last two centuries, ranging from lath and plaster to cement wallboard, to cellulose drywall, and mildew-resistant green board. Some of the constituents of these materials are predisposed to mold growth because the constituents represent a potential food source for mold colonies. The nature of the loss was also a limitation, since hurricanes or other catastrophic flooding events were eliminated by selection to projects within a climate zone that historically did not experience this type of weather occurrence. Therefore, the projects included in this study were more representative of the casual and common water loss and mold events that occur in residential homes.

There were also limitations in the analytical methods used in this study. Logistic regression was used to analyze the nominal dichotomous dependent variables of the study and adjust for confounding variables to provide a predictive measure of association for an outcome based on one or more additional variables. For example, the likelihood that a project would be successful if containment were used, or the likelihood that a project would be successful if the contractor followed consensus documents, were two main types of meaningful information resulting from this study with direct practical application to the field. However, since this statistical method could not predict the numerical count of mold spores in the air, this was an acceptable limitation of the study. As of 2020, current air quality standards fail to designate an acceptable level of mold exposure and exposure limits for mold spores do not exist, although it is known that exposure to airborne mold spores is linked with an increased risk of poor respiratory health for some building occupants (CDPH, 2019; IOM, 2004; WHO-EUR, 2009). Therefore, it was assumed fewer mold spores in the air related to a reduced risk, the analysis of this study only allowed a determination of whether the spores present in post-remediation testing were influenced by independent variables such as work practices and various engineering controls. The scope of the study and analysis methods prevented the correlation of lower mold counts or passing reports to a healthier or safer environment.

The lack of standardized operating procedures for enumerating mold spores on spore traps has been identified as a problem in laboratory reporting (Hung, Miller, & Dillon, 2005). In addition, Godish and Godish (2007) discussed spore counting procedures and revealed the discrepancy in counts depending on analyst magnification, whereas the research of Kleinheinz, Langolf, and Englebert (2006) used (spores/m^3) to quantify mold spores. In an effort to reduce sampling errors, the final limitation of the study was the use of the raw count of mold spores identified by laboratory analysts since different laboratories use different microscopes and analyzing power, and some laboratories have a proprietary methodology for calculating mold spores per cubic meter of air (spores/m^3). With consideration for the differences between laboratories, microbiology laboratories use a methodology that aligns to a standardized ISO method of identification and enumeration with the limit of detection defined as the product of a raw count of one and 100, divided by the percent read. The analytical sensitivity (counts/m^3) represents the product of the limit of detection and 1000, divided by the sample volume. While the (spores/m^3) number was available and maybe useful, the raw count was used in this study to eliminate the variation in computation from different laboratories, which possibly limited the applicability of the study results.

Delimitations

The selection process for projects included in this research inherently introduced several delimitations. For this study, one main delimitation was the restriction of projects to the type of construction (i.e., residential buildings) in southern California, and by restricting the selection of geography and construction type, confounding variables like the use of dissimilar building materials were lessened, thus increasing the validity of the study results and diminished unmeasured confounding. In addition, climate can vary with geographic location, which represented a potential confounding variable, and restricting selected projects to those located in southern California, the climate range was consistent across all the projects, which eliminated the wide range of rain fall and high humidity that was consistent with another climate and geographic location. Projects that may have experienced significant flooding from rivers or hurricane-type conditions that exist in other climate regions. Flooding, hurricanes, high humidity, and annual rainfall may present environmental conditions that could affect airborne mold spore counts and these types of catastrophic weather events could introduce addition complexities. Therefore, the delimitation to restrict projects in this study to residential buildings was utilized for several additional reasons. For instance, residential structures in southern California have similar ventilations systems, mechanical ventilation is responsible for conditioning and filtering air, and ventilation systems are also responsible for the mix of fresh air into buildings. Further, ventilation in residential buildings of California are generally closed systems, in that they do not add a mix of fresh outside air to the system and the return vent is in the residence, and the air inside the residence is circulated and recirculated through the same system for conditioning and filtration. Depending on the age of the building, many homes in southern California do not have mechanical ventilation and the ventilation type is often omitted in IEP reports and may not be known.

Another important delimitation was the restriction of the mold sport count type to utilize in the study regarding the general assumptions used for the airborne mold spore count. Laboratories report raw count and total count (spore/m^3) and each laboratory is responsible for the calculations from raw count to (spore/m^3). Therefore, to avoid discrepancies in enumeration, the total raw count is used rather than the (spore/m^3). Since the laboratory analyst identifies the type of mold present and then enumerates the findings, the raw count is fixed although one laboratory may calculate seven in raw count of mold spores as total spore count (370/m^3), another lab may calculate seven in raw count of mold spores as total spore count (91/m^3). The discrepancies in calculation may make a project appear more severely affected by mold or having more airborne mold spores. Holding the assumption that few more spores equates to a reduced risk of poor health outcomes, it was important to use a consistent level of measurement for airborne mold spores and use only raw mold spore count.

Ethical Assurances

The dissertation research used existing historical secondary data, and no human subjects were included in the study. An IRB approval (Appendix D) was obtained from Trident University International through a secondary data use exemption. In addition, a letter of approval was obtained to gain access to AQTS project data before the execution of the study (Appendix E). Each of the documents pertaining to ethical assurances are included in the Appendices.

Summary

A quantitative, nonexperimental correlational design using secondary data was selected to execute the retrospective dissertation research study. The data obtained from IEP reports and laboratory analyses were used to explore the association between work practices employed in water damage restoration and mold remediation projects and the successful outcome of the projects. Several covariates were introduced into the analyses to predict the outcome variables of pass-fail and spore count and the results of this study were not intended for establishing cause-and-effect. While the data in each IEP report and laboratory report can be replicated, the conditions at the time of post-remediation verification and clearance testing cannot be replicated. Therefore, the assessment and testing for each project represents a single snapshot in time. Exposure limits for airborne mold spores in residential buildings in California do not exist, although it is known that exposure to damp and moldy buildings increases the risk of poor health outcomes for building occupants. The underlying assumptions guiding the research were that fewer airborne mold spores equate to a reduced risk of poor health outcomes, and that there was a measurable relationship between remediation work practices, mold spore count, and successful project outcomes.

Chapter IV: Data Analysis and Results

The purpose of the study was to explore the relationship between how water damage mitigation and mold remediation work was performed and the project outcome as evaluated by the IEP report and raw airborne mold spore count in the work area. Although as of 2020, there were no data like this in existence, secondary data was used to create a dataset from IEP reports, project reports, job notes, photographs, and laboratory reports. The data were collected in the form of a survey and digital files containing project information and since no centralized data existed, data were mined by hand and populated into a Microsoft Excel spreadsheet, which imported into Intellectus Statistics software for the statistical analysis. There were 267 projects included in the dataset which comprised information from five unique IEPs, five unique microbiology laboratories, and eight unique contractors. Each of the projects were residential properties that experienced water damage mitigation or mold remediation in southern California, defined as San Diego, Orange, Los Angeles, Riverside, San Bernardino, and Imperial Counties.

Data Screening

The primary independent variable ‘work’ and two dependent variables ‘spore’ and ‘pass-fail’ were required for a project to be included in the dataset, and if these variables were not present, then the project was eliminated from the sample. There were a number of outliers in ‘spore’ that included a count in the work area, count in the adjacent or unaffected area, and outside area that did not follow a Gaussian distribution and showed heteroscedasticity. Several influential points were present on studentized residual plots, and the non-Gaussian distribution of the data influenced the type of analyses that were used. Some variables like temperature and relative humidity were not included in the PRV and therefore could not be included in the dataset. Missing data were common in some variables including ‘temperature,’ relative ‘humidity,’ ‘non-affected spore,’ ‘debris,’ and ‘decontamination’ chamber. Therefore, the observations for these variables were omitted when values were absent. In addition, missing data restricted some multivariate analyses, such as the ANOVA replaced with the Kruskal-Wallis test, and the use other statistical tests that permitted the assessment of non-Gaussian data distributions.

Descriptive Statistics

Frequencies and percentages were calculated for each nominal and ordinal variable of the study, whereas summary statistics were calculated for each interval and ratio variable.

Frequency and percentage estimates. Out of the 267 projects that were included in the analyses, approximately nine percent of all projects did not follow consensus documents, 17% partially followed consensus documents, and 74% did follow consensus documents. Nearly 78% of projects passed PRV with 22% failing and containments in good condition were present in 76% of all the projects. Air filtration devices were used in 79% of projects with three percent having an AFD and dehumidifier present, 15% of projects having no equipment present, less than one percent of projects having only a dehumidifier present, and three percent of projects with missing data. Approximately 78% of contractors were remediation contractors, about 17% were general contractors, and less than six percent were handymen and maintenance workers. The average year or ‘age’ of built construction was 2008 and approximately 13% of projects had the mold type, *Stachybotrys,* present in the airborne mold sample collected in the work area.

Table 6 shows the frequency estimates for the ‘IEP,’ ‘work,’ and ‘pass-fail’ variables.

Table 6

Frequency of IEP, Work, and Pass-Fail

Variable	*n*	%
IEP		
1	231	86.52
2	23	8.61
3	1	0.37
4	4	1.5
5	8	3
Missing	0	0
Work		
1	24	8.99
2	45	16.85
3	198	74.16
Missing	0	0
Pass-fail		
Pass	207	77.53
Fail	60	22.47
Missing	0	0

Note. IEP = Indoor Environmental Professional.

The frequency estimates for the ‘contractor,’ ‘lab,’ and ‘containment’ variables are shown in Table 7.

Table 7

Frequency of Contractor, Lab, and Containment

Variable	*n*	%
Contractor		
1	207	77.53
2	45	16.85
3	15	5.62
Missing	0	0
Lab		
1	139	52.06
2	64	23.97
3	56	20.97
4	6	2.25
5	2	0.75
Missing	0	0
Containment		
1	204	76.4
2	9	3.37
3	8	3
4	46	17.23
Missing	0	0
Decontainment		
No	218	81.65
Yes	41	15.36
Missing	8	3

Table 8 shows the frequency estimates for the 'equipment,' 'affect-mat,' 'damp,' 'retest,' 'debris,' and 'mold-stachy' project condition variables.

Table 8

Frequency of Project Condition Variables

Variable	*n*	%
Equipment		
1	211	79.03
2	7	2.62
3	40	14.98
4	1	0.37
Missing	8	3
Affect-mat		
No	242	90.64
Yes	17	6.37
Missing	8	3
Damp		
No	251	94.01
Yes	8	3
Missing	8	3
Retest		
No	223	83.52
Yes	44	16.48
Missing	0	0
Debris		
1	19	7.12
1+	9	3.37
2	40	14.98
2+	25	9.36
3	147	55.06
3+	14	5.24
4	2	0.75
4+	2	0.75
Missing	9	33.37
Mold-stachy		
No	232	86.89
Yes	35	13.11
Missing	0	0

The frequency estimates for the ‘month’ of assessment variable is shown in Table 9.

Table 9

Frequency of Month

Variable	*n*	%
Month		
January	53	19.85
February	22	8.24
March	24	8.99
April	17	6.37
May	18	6.74
June	12	4.49
July	15	5.62
August	26	9.74
September	20	7.49
October	14	5.24
November	15	5.62
December	31	11.61
Missing	0	0

Table 10 shows the frequency estimates for the ‘age’ variable representing the year of which each structure was built.

Table 10

Frequency of Age

Variable	*n*	%	Variable	*n*	%
Age			Age		
1924	1	0.37	1987	3	1.12
1927	1	0.37	1988	10	3.75
1935	2	0.75	1989	11	4.12
1938	1	0.37	1990	4	1.5
1944	1	0.37	1991	6	2.25
1947	2	0.75	1992	10	3.75
1960	3	1.12	1994	4	1.5
1961	2	0.75	1995	1	0.37
1962	2	0.75	1996	2	0.75
1964	1	0.37	1997	1	0.37
1970	1	0.37	1998	6	2.25
1971	1	0.37	1999	2	0.75
1972	4	1.5	2000	7	2.62
1973	3	1.12	2001	8	3
1974	4	1.5	2002	6	2.25
1975	6	2.25	2003	12	4.49
1976	2	0.75	2004	8	3
1977	4	1.5	2005	7	2.62
1978	2	0.75	2006	9	3.37
1979	4	1.5	2007	8	3
1980	5	1.87	2008	54	20.22
1983	4	1.5	2009	5	1.87
1984	4	1.5	2010	3	1.12
1985	7	2.62	2016	1	0.37
1986	3	1.12	Missing	9	3.37

Note. (*n* = 267) projects.

Summary statistics. The average temperature, value of relative humidity, number of airborne mold spores in the work area were 77°F, 45%, and 39 raw count, respectively. In the adjacent non-affected area, the mean number of airborne mold spores was 41 raw count, although there were 102 missing observations in the 'NAA-spore' variable, whereas the mean number of airborne mold spores was 77 raw count. Average count for hyphae in the work area was 30 (hyphae/m^3), though there were 141 missing observation and some significant outliers for the 'hyphae' variable.

The summary statistics for the interval and ratio variables are shown in Table 11. As a skewness estimate increases greater than an absolute value of two, the observations for the variable are considered being asymmetrical about the mean value. Similarly, as a kurtosis estimate increases to a value of three or greater, the distribution of observations for the variable and the tendency to produce outliers were markedly different compared to a normal distribution. The univariate distributions for 'spore,' 'NAA-spore,' 'outside,' and 'hyphae' were non-normal and highly skewed, representing the bolded variables in Table 11.

Table 11

Summary Statistics for Interval and Ratio Variables

Variable	*M*	*SD*	*n*	*SEM*	*Min*	*Max*	*Skewness*	*Kurtosis*
Temperature	77.30	7.21	169	0.55	55.00	100.00	0.08	0.18
Humidity	44.89	11.64	169	0.90	17.00	74.00	-0.11	-0.27
Spore	**34.39**	86.65	267	5.30	0.00	679.00	**5.20**	**31.24**
NAA-spore	**40.60**	50.93	168	3.93	0.00	288.00	**2.72**	**8.81**
Outside-spore	**77.26**	91.22	264	5.61	3.00	756.00	**3.97**	**22.82**
Hyphae	**30.20**	46.75	224	3.12	0.00	260.00	**2.22**	**5.47**

Bivariate Analyses

A significance threshold ($\alpha = 0.05$) was established for null hypothesis significance testing for each of the hypotheses in this study.

RQ1. Is there an association between the airborne mold spore count in the work area and the pass-fail assessment of the IEP?

H_{01}. There is no association between the airborne mold spore count in the work area and the pass-fail assessment of the IEP.

H_{a1}. There is an association between the airborne mold spore count in the work area and the pass-fail assessment of the IEP.

A two-tailed Mann-Whitney *U* two-sample rank-sum test was conducted to examine whether there were significant differences in spore count between the levels of 'pass-fail'. The two-tailed Mann-Whitney two-sample rank-sum test is an alternative to the independent samples *t*-test that does not share the same assumptions (Conover & Iman, 1981).

There were 207 observations in the 'pass' group and 60 observations in the 'fail' group. The results of the two-tailed Mann-Whitney *U* test showed a significant effect, $U = 1807$, $z = -8.37$, $p < .001$. Hence, the null hypothesis was rejected. The mean rank for the 'pass' group was 112.73 and the mean rank for 'fail' group was 207.38, which suggests that the distribution of 'spore' for the 'pass' group was significantly different from the distribution of 'spore' for the 'fail' group. The median for 'pass' (*Mdn* = 5.00) was significantly lower than the median for 'fail' (*Mdn* = 53.50). Table 12 presents the results of the two-tailed Mann-Whitney *U* test and Figure 4 shows a boxplot of the ranks of 'spore' by 'pass-fail.'

The bivariate analysis confirmed an association between the total raw spore count of airborne mold spores in the work area and the pass or fail assessment of the IEPs. Projects with lower counts of airborne mold spores were more likely to pass the IEP assessment, whereas projects with higher counts of mold spores were more likely to fail the IEP assessment.

Table 12

Two-Tailed Mann-Whitney Test for Spore by Pass-Fail

	Mean Rank				
Variable	Pass	Fail	*U*	*z*	*p*
Spore	112.73	207.38	1807.00	-8.37	< .001

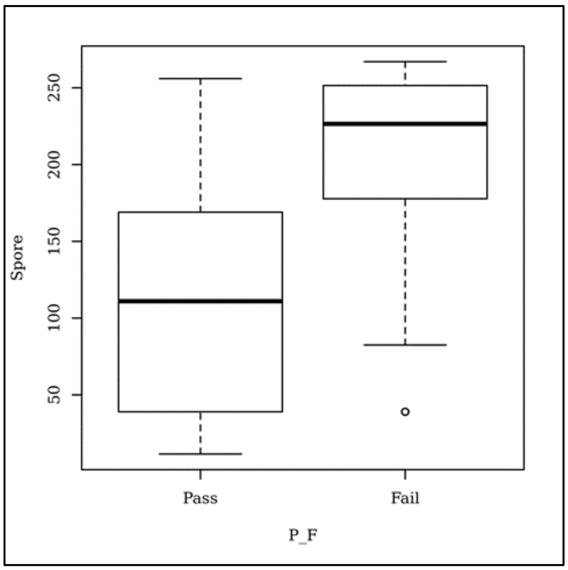

Figure 4. Ranks of spore by pass-fail.

RQ3. Is there an association between the pass-fail assessment of the IEP and how closely the work follows consensus document guidelines?

H_{03}. There is no association between the pass-fail assessment of the IEP and how the work is performed.

H_{a3}. There is an association between the pass-fail assessment of the IEP and how the work is performed.

A chi-square test of independence was conducted to examine whether ‘pass-fail’ and ‘work’ were independent. There were two levels in the pass-fail (1 = pass, 2 = fail) and three levels for work (1 = did not follow consensus, 2 = partially followed consensus, 3 = did follow consensus).

The assumption of adequate cell size was assessed, which required all cells to have expected values greater than zero and 80% of cells to have expected values of at least five (McHugh, 2013). Each of the cells had expected values greater than zero, indicating the first condition was met, and a total of 100% of the cells had expected frequencies of at least five, indicating the second condition was met.

The results of the chi-square test showed a significant association between the two variables, $\chi^2(2) = 72.75$, $p < .001$, which suggests that 'pass-fail' and 'work' were dependent. Hence, the null hypothesis was rejected. The level combinations for (1 + fail, 2 + fail, and 3 + fail) contained observed values that were greater than their expected values, whereas the level combinations for (1 + pass, 2 + pass, 3 + pass) contained observed values that were less than their expected values. Table 13 presents the results of the chi-square test.

The bivariate analysis confirmed an association between how closely the work follows consensus document guidelines and the pass or fail assessment of IEPs. Projects that did not follow consensus document guidelines and projects that only partially followed consensus document guidelines were more likely to fail the assessment, whereas the projects that closely followed consensus document guidelines were more likely to pass the assessment.

Table 13

Chi-Square Test for Work and Pass-Fail

	Pass-fail				
Work	Pass	Fail	χ^2	*df*	*p*
1	5 [18.61]	19 [5.39]	72.75	2	< .001
2	25 [34.89]	20 [10.11]			
3	177 [153.51]	21 [44.49]			

Note. Values formatted as observed [expected].

Multivariate Analyses

RQ2. Is there an association between the airborne spore count in the work area and how closely the work follows consensus document guidelines?

H_{02}. There is no association between the airborne spore count in the work area and how the work is performed.

H_{a2}. There is an association between the airborne spore count in the work area and how the work is performed.

A Kruskal-Wallis rank sum test was conducted to determine if there were significant differences in 'spore' count between levels of 'work.' Given the univariate distributions of each variable, the Kruskal-Wallis test was selected as a non-parametric alternative to the one-way ANOVA that did not share the same distributional assumptions (Conover & Iman, 1981). There were three levels in the work variable (1 = did not follow consensus, 2 = partially followed consensus, 3 = did follow consensus).

The results of the Kruskal-Wallis test showed a significant difference in the mean rank of 'spore' across levels of the 'work' variable, $\chi^2(2) = 53.23$, $p < .001$, hence, the null hypothesis was rejected. The results of the Kruskal-Wallis rank sum test are shown in Table 14. The boxplot of the ranked values of 'spore' by the levels of 'work' are shown in Figure 5.

The multivariate analysis confirmed an association between how closely the work followed consensus document guidelines and the total airborne mold spore count in the work area following remediation. Work that did not follow consensus document guidelines had a higher mean rank of mold spores than work that partially followed consensus document guidelines, whereas the work that more closely followed consensus document guidelines had the lowest mean rank for spore. Given these results, it was concluded that work practices that follow consensus document guidelines are more likely to achieve fewer airborne mold spores in the work area than work that does not or partially follow consensus document guidelines.

Table 14

Kruskal-Wallis Rank Sum Test for Spore by Work

Level	Mean rank	χ^2	*df*	*p*
1	212.31	53.23	2	$< .001$
2	179.17			
3	114.24			

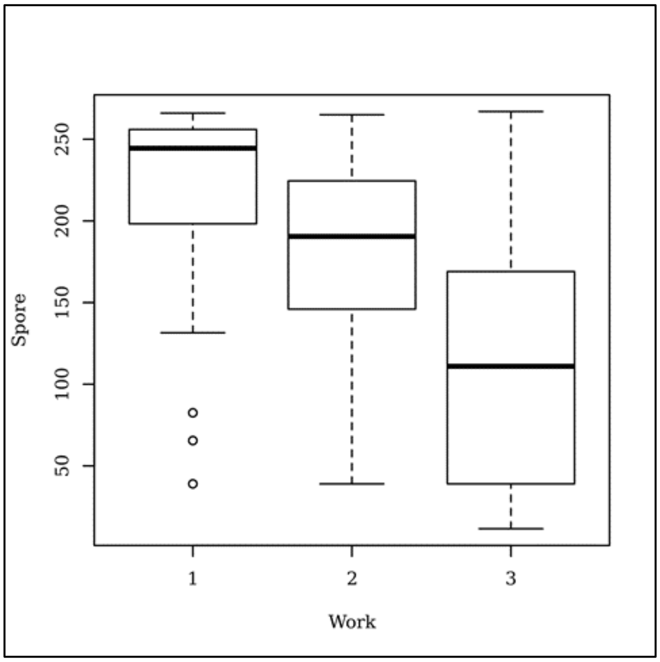

Figure 5. Ranked values of spore by levels of work.

Post-hoc pairwise comparisons were examined between each level of 'work'. The results of the multiple comparisons indicated significant differences between the variable pairs (1-3, 2-3). Table 15 show the results of each pairwise comparison.

Table 15

Pairwise Comparisons for the Mean Ranks of Spore by Work

Comparison	Observed difference	Critical difference
1-2	33.15	46.73
1-3	98.07	39.96
2-3	64.92	30.53

Note. Observed differences greater than critical differences indicate significance at the $p < .05$ level.

RQ4. Is there an association between how work is performed, contractor type, containment, and the fail outcome of the pass-fail assessment?

H_{04}. There is no association between how work is performed, contractor type, containment, and the fail outcome of the pass-fail assessment.

H_{a4}. There is an association between how work is performed, contractor type, containment, and the fail outcome of the pass-fail assessment.

During the execution of the study, several variable relationships became evident. Therefore, additional research questions and statistical hypotheses were developed a posteriori beginning with research question four, and although research question four was not conceptualized a priori, it was included in the main analysis section given the merit of the analysis in understanding the variable relationships and the entirety of the dissertation research. Specifically, research question four was devised to find whether three main predictors influenced the odds of a nominal dichotomous dependent variable of the study.

A binomial logistic regression was used to determine the odds of failing the 'pass-fail' assessment using 'work,' 'contractor,' and 'containment' as predictors. The reference category for 'pass-fail' was (1 = pass). The assumption of the absence of multicollinearity was examined by calculating variance inflation factors (VIFs) to detect the presence of multicollinearity between the predictors. High VIFs indicate an increased multicollinearity or correlation among the predictors of a model. Correlated predictors, VIFs greater than five, represent some concern as the values increase, whereas highly correlated predictors with VIFs greater than 10 represent the maximum upper limit and a cause for concern since this leads to issues in interpreting the explained variance of the model (Menard, 2009). The VIFs for each predictor of the model was less than five, the threshold of initial concern (Table 16).

Table 16

Variance Inflation Factors for Work, Contractor, and Containment

Variable	VIF
Work	3.35
Contractor	2.63
Containment	3.54

The overall logistic regression model fit with the outcome ‘pass-fail’ and the predictors ‘work,’ ‘contractor,’ and ‘containment’ was significantly better, $\chi^2(7) = 71.03$, $p < .001$, than a null model with only one of the predictors, which showed one of more predictors contributed to the model. Therefore, the null hypothesis was rejected. To gain more direct information on the fit of the model, a McFadden’s R^2 test was used to estimate a measure of the model fit with values (> 0.20) showing evidence of excellent model fit (Louviere, Hersher, & Swait, 2000). The McFadden’s R^2 tested yielded a value the model of 0.25 showing the model was indicative of excellent fit.

The regression coefficient for ‘Work-2’ was significant, $B = -2.13$, $OR = 0.12$, $p = .004$, indicating that for a one unit increase in ‘Work-2,’ the odds of observing the ‘fail’ category of ‘pass-fail’ would decrease by approximately 88%. The regression coefficient for ‘Work-3’ was significant, $B = -4.74$, $OR = 0.01$, $p < .001$, indicating that for a one unit increase in ‘Work-3,’ the odds of observing the ‘fail’ category of ‘pass-fail’ would decrease by approximately 99%.

The regression coefficient for ‘Contractor-2’ was not significant, $B = -0.98$, $OR = 0.38$, $p = .114$, indicating that ‘Contractor-2’ did not have a significant effect on the odds of observing the ‘fail’ category of ‘pass-fail.’ The regression coefficient for ‘Contractor-3’ was not significant, $B = 0.28$, $OR = 1.33$, $p = .750$, indicating that 'Contractor-3' did not have a significant effect on the odds of observing the 'fail' category of 'pass-fail.'

The regression coefficient for Containment-2 was not significant, $B = -0.42$, $OR = 0.66$, $p = .662$, indicating that 'Containment-2' did not have a significant effect on the odds of observing the 'fail' category of 'pass-fail.' The regression coefficient for 'Containment-3' was not significant, $B = -0.62$, OR = 0.54, $p = .488$, indicating that 'Containment-3' did not have a significant effect on the odds of observing the 'fail' category of 'pass-fail.' The regression coefficient for 'Containment-4' was not significant, $B = -0.80$, OR = 0.45, $p = .264$, indicating that 'Containment-4' did not have a significant effect on the odds of observing the 'fail' category of 'pass-fail.' Table 17 summarizes the results of the regression model.

Table 17

Logistic Regression of Predictors of Pass-Fail

Pass-Fail	*B*	*SE*	95% CI	χ^2	*p*	*OR*
(Intercept)	2.68	0.89	[0.95, 4.42]	9.17	.002	
Work-2	-2.13	0.74	[-3.58, -0.69]	8.38	.004	0.12
Work-3	-4.74	0.90	[-6.50, -2.98]	27.94	< .001	0.01
Contractor-2	-0.98	0.62	[-2.19, 0.24]	2.50	.114	0.38
Contractor-3	0.28	0.89	[-1.46, 2.03]	0.10	.750	1.33
Containment-2	-0.42	0.97	[-2.32, 1.47]	0.19	.662	0.66
Containment-3	-0.62	0.89	[-2.35, 1.12]	0.48	.488	0.54
Containment-4	-0.80	0.72	[-2.21, 0.61]	1.25	.264	0.45

Note. $\chi^2(7) = 71.03$, $p < .001$, McFadden $R^2 = 0.25$, CI = confidence interval for odds ratios (OR).

Exploratory Analyses

Several exploratory analyses were conducted to gain better understanding of the relationships between the covariates and dependent variables. The relationships between project outcomes and characteristics, engineering controls, and environmental conditions were investigated in an effort to find significant associations with the project outcome as evaluated by an IEP and airborne mold spore count in the work area. Each of the variables in these categories were analyzed to determine if there were significant effects on the outcome variables: IEP 'pass-fail' Assessment and the total airborne 'spore' count in the work area during post-remediation verification assessment.

Project Characteristic Analyses

Exploratory-RQ1. Is there a statistically significant relationship between pass-fail and contractor?

Exploratory-H_{01}. There is no significant relationship between pass-fail and contractor.

Exploratory-H_{a1}. There is a significant relationship between pass-fail and contractor.

A chi-square test of independence was conducted to examine whether 'pass-fail' and 'contractor' were independent. There were two levels in 'pass-fail' (1 = pass, 2 = fail) and three levels in contractor (1 = remediator, 2 = general contractor, 3 = handyman or maintenance worker). The assumption of adequate cell size was assessed, which required all cells to have expected values greater than zero and 80% of cells to have expected values of at least five (McHugh, 2013). Each of the cells had expected values greater than zero, indicating the first condition was met. A total of 83.33% of the cells had expected frequencies of at least five, indicating the second condition was met.

The results of the chi-square test were significant, $\chi^2(2) = 25.58$, $p < .001$, suggesting that 'pass-fail' and 'contractor' were dependent. Hence, the null hypothesis was rejected. The level combinations with observed values that were greater than expected values included (1 + pass, 2 + fail, 3 + fail), whereas the level combinations with observed values that were less than the expected values were (1 + fail, 2 + pass, 3 + pass). The results of the chi-square test are shown in Table 18.

Table 18

Chi-Square Results for Contractor and Pass-Fail

	Pass-fail				
Contractor	Pass	Fail	χ^2	*df*	*p*
1	173 [160.48]	34 [46.52]	25.58	2	< .001
2	29 [34.89]	16 [10.11]			
3	5 [11.63]	10 [3.37]			

Note. Values formatted as observed [expected].

Exploratory-RQ2. Is there an association between the airborne spore count in the work area and the contractor?

Exploratory-H$_{02}$. There is no association between spore and contractor.

Exploratory-H$_{a2}$. There is an association between spore and contractor.

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in 'spore' between the levels of 'contractor.' The Kruskal-Wallis test represents a non-parametric alternative to the one-way ANOVA that does not share the same distributional assumptions (Conover & Iman, 1981).

The results of the Kruskal-Wallis test were significant, $\chi^2(2) = 34.78$, $p < .001$, indicating that the mean rank of ‘spore’ was significantly different between the levels of ‘contractor.’ Hence, the null hypothesis was rejected. Table 19 includes the results of the Kruskal-Wallis rank sum test and Figure 6 presents boxplots of the ranked values of ‘spore’ by the levels of ‘contractor.’

Table 19

Kruskal-Wallis Rank Sum Test for Spore by Contractor

Level	Mean rank	χ^2	*df*	*p*
1	119.45	34.78	2	< .001
2	176.17			
3	208.30			

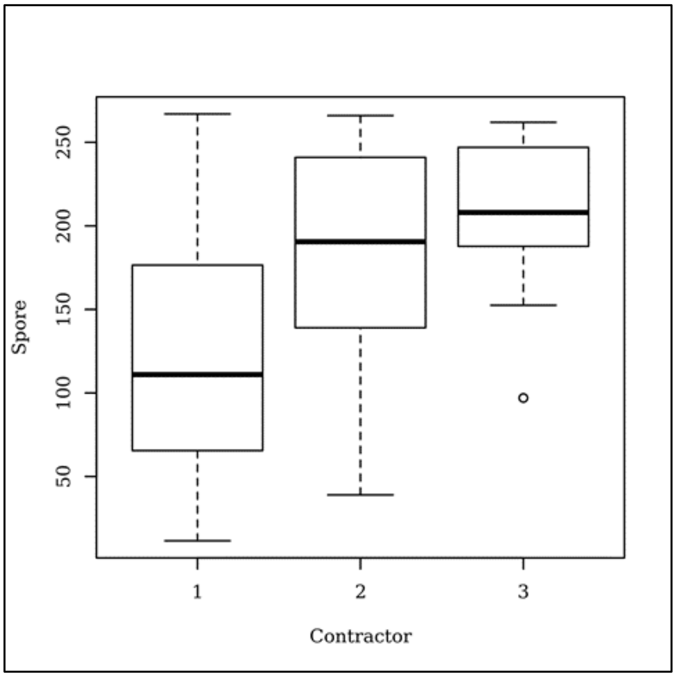

Figure 6. Ranked values of spore by contractor type.

Post-hoc pairwise comparisons were examined between each level of ‘contractor.’ The multiple comparisons indicated significant differences between the mean ranks of spores and level pairs (1-2, 1-3). Table 20 shows the results of the pairwise comparisons.

Table 20

Pairwise Comparisons for the Mean Ranks of Spore by Contractor Type

Comparison	Observed difference	Critical difference
1-2	56.72	30.41
1-3	88.85	49.43
2-3	32.13	55.12

Note. Observed differences greater than critical differences indicate significance at the $p < 0.05$ level.

Exploratory-RQ3. Is there an association between the pass-fail assessment and the age of the structure?

Exploratory-H$_{03}$. There is no association between pass-fail and age.

Exploratory-H_{a3}. There is an association between pass-fail and age.

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in 'age' between the levels of 'pass-fail.' The Kruskal-Wallis test represents a non-parametric alternative to the one-way ANOVA that does not share the same distributional assumptions (Conover & Iman, 1981).

The results of the Kruskal-Wallis test were not significant, $\chi^2(1) = 1.05$, $p = .306$, indicating that the mean rank of 'age' was similar for each level of 'pass-fail.' The results of the Kruskal-Wallis rank sum test are shown in Table 21 and boxplots of the ranked values of 'age' by the levels of 'pass-fail' are shown in Figure 7.

Table 21

Kruskal-Wallis Rank Sum Test for Age by Pass-Fail

Level	Mean rank	χ^2	*df*	*p*
Pass	132.02	1.05	1	.306
Fail	120.61			

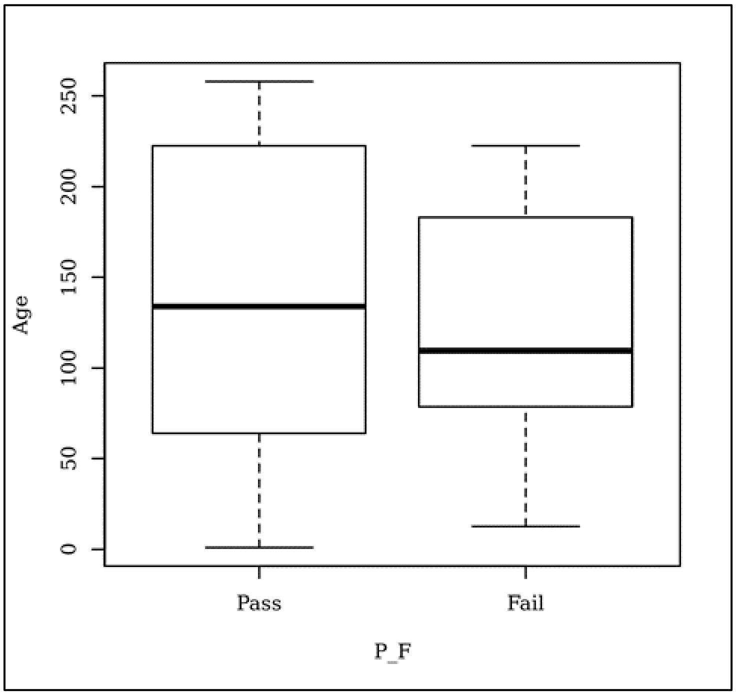

Figure 7. Ranked values of age by the levels of pass-fail.

Exploratory-RQ4. Is there a correlation between the airborne mold spore count in the work area and the age of the structure?

Exploratory-H_{04}. There is no correlation between spore and age.

Exploratory-H_{a4}. There is a correlation between spore and age.

A Kendall correlation analysis was conducted between 'spore' and 'age.' Cohen's standard was used to evaluate the strength of the relationship, considering coefficients between (0.10 and 0.29) to represent a small effect size, coefficients between (0.30 and 0.49) to indicate a moderate effect size, and coefficients above (0.50) to represent a large effect size (Cohen, 1988). A Kendall correlation requires and rests on the assumption that the relationship between each pair of variables does not change direction (Millard & Neerchal, 2000). The assumption is violated if the points on the scatterplot between any pair of variables appear to shift from a positive to negative or negative to positive relationship. Figure 8 shows the scatterplot of the correlation with an added regression line to assist the interpretation.

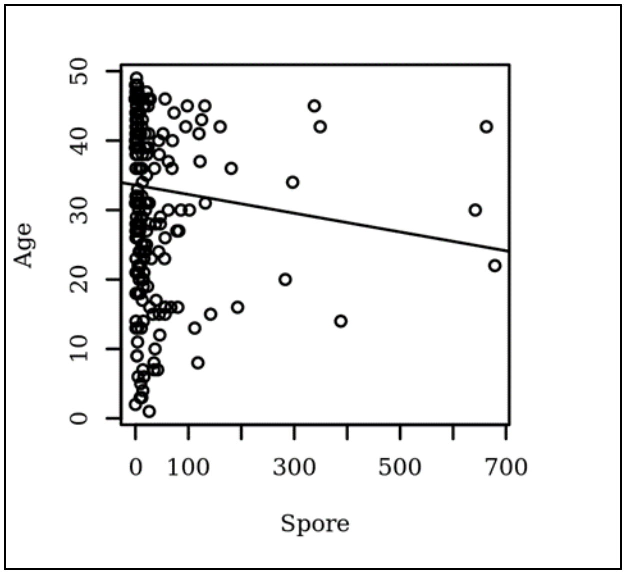

Figure 8. Scatterplot of age and spore correlations.

A significant negative correlation was observed between 'spore' and 'age' (r_k = -0.30, $p < .001$) indicates that as 'spore' increases, 'age' tends to decrease while the correlation coefficient magnitude (-0.30) shows a small effect size. The results of the correlation are shown in Table 22.

Table 22

Kendall Correlation between Spore and Age

		95% CI		
Combination	r_k	LL	UL	p
Spore-Age	-0.30	-0.40	-0.18	< .001

Note. The confidence interval was computed using ($\alpha = 0.05$; $n = 258$).

Exploratory-RQ5. Is there an association between the pass-fail assessment and the month the assessment was completed?

Exploratory-H_{05}. There is no association between pass-fail and month.

Exploratory-H_{a5}. There is an association between pass-fail and month.

A chi-square Test of Independence was conducted to examine whether 'month' and 'pass-fail' were independent. There were two levels in 'pass-fail' (1 = pass, 2 = fail) and 12 levels in 'month' that corresponded to each month of the year (January, February, March, April, May, June, July, August, September, October, November, December).

The assumption of adequate cell size was assessed, which requires all cells to have expected values greater than zero and 80% of cells to have expected values of at least five (McHugh, 2013). Each of the cells had expected values greater than zero, indicating the first condition was met, although 66.67% of the cells had expected frequencies of at least five, indicating the second condition was violated. Since the assumptions of the chi-square test were violated, the Fisher's exact test was used to produce more reliable results with small sample sizes, although logit models such as binary logistic regression could have been employed, but usually reserved for larger sample sizes.

The results of the chi-square test were significant, $\chi^2(11) = 24.29$, $p = .012$, suggesting that 'month' and 'pass-fail' are dependent. The level combinations of (1 + March, 1 + January, 1 + October, 1 + November, 1 + December, 1 + February, 2 + April, 2 + June, 2 + July, 2 + August, 2 + September, 2 + May) resulted in observed values that were greater than the expected values, whereas the level combinations of (1 + April, 1 + June, 1 + July, 1 + August, 1 + September, 1 + May, 2 + March, 2 + January, 2 + October, 2 + November, 2 + December, and 2 + February) resulted in observed values that were less than the expected values (Table 23).

Table 23

Chi-Square Test for Month and Pass-Fail

	Pass-fail				
Month	Pass	Fail	χ^2	*df*	*p*
January	48 [41.09]	5 [11.91]	24.29	11	.012
February	19 [17.06]	3 [4.94]			
March	19 [18.61]	5 [5.39]			
April	10 [13.18]	7 [3.82]			
May	9 [13.96]	9 [4.04]			
June	8 [9.30]	4 [2.70]			
July	11 [11.63]	4 [3.37]			
August	20 [20.16]	6 [5.84]			
September	12 [15.51]	8 [4.49]			
October	11 [10.85]	3 [3.15]			
November	13 [11.63]	2 [3.37]			
December	27 [24.03]	4 [6.97]			

Note. Values formatted as observed [expected].

The Fisher's exact test was conducted to examine whether 'month' and 'pass-fail' were independent. For variables with a large number of categories or observations, the Fisher's exact test is computationally intensive, and as a result, Monte-Carlo simulations were used to estimate a *p* value instead of an exact *p* value. The results of the Fisher exact test were significant, $p =$ .008, suggesting that 'month' and 'pass-fail' were related to one another. The level combinations of (1 + March, 1 + January, 2 + April, 2 + June, 2 + July, 2 + August, 1 + October, 1 + November, 1 + December, 1 + February, 2 + September, and 2 + May) showed observed values that were greater than their expected values, whereas the level combinations of (2 + March, 2 + January, 1 + April, 1 + June, 1 + July, 1 + August, 2 + October, 2 + November, 2 + December, 2 + February, 1 + September, 1 + May) showed observed values that were less than the expected values (Table 24).

Table 24

Fisher's Exact Test for Month and Pass-Fail

	Pass-fail		
Month	Pass	Fail	*p*
January	48 [41.09]	5 [11.91]	.008
February	19 [17.06]	3 [4.94]	
March	19 [18.61]	5 [5.39]	
April	10 [13.18]	7 [3.82]	
May	9 [13.96]	9 [4.04]	
June	8 [9.30]	4 [2.70]	
July	11 [11.63]	4 [3.37]	
August	20 [20.16]	6 [5.84]	
September	12 [15.51]	8 [4.49]	
October	11 [10.85]	3 [3.15]	
November	13 [11.63]	2 [3.37]	
December	27 [24.03]	4 [6.97]	

Note. Values formatted as observed [expected].

Exploratory-RQ6. Is there an association between the airborne mold spore count in the work area and the month the assessment was completed?

Exploratory-H_{06}. There is no association between spore and month.

Exploratory-H_{a6}. There is an association between spore and month.

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in ‘spore’ between the levels of ‘month,’ as a non-parametric alternative to the one-way ANOVA that did not share the same distributional assumptions (Conover & Iman, 1981).

The results of the Kruskal-Wallis test were significant, $\chi^2(11) = 56.34$, $p < .001$, indicating that the mean rank of ‘spore’ was significantly different between the levels of ‘month.’ The results of the Kruskal-Wallis rank sum test are shown in Table 25 and boxplots of the ranked values of ‘spore’ by the levels of ‘month’ are shown in Figure 9.

Table 25

Kruskal-Wallis Rank Sum Test for Spore by Month

Level	Mean Rank	χ^2	*df*	*p*
January	102.65	56.34	11	< .001
February	153.66			
March	169.06			
April	174.74			
May	185.47			
June	91.83			
July	141.73			
August	142.75			
September	184.35			
October	134.14			
November	88.27			
December	89.10			

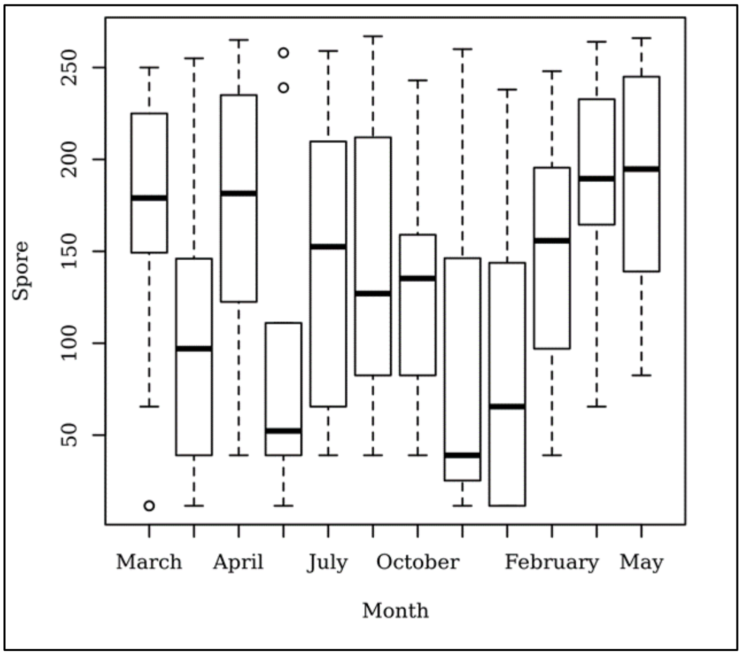

Figure 9. Ranked values of spore by the levels of month.

Post-hoc pairwise comparisons were examined between the mean ranks of 'spore' at each level of 'month' resulting in significant differences between the variable level pairs of (March-January, March-December, January-September, January-May, April-December, November-September, November-May, December-September, December-May). The pairwise comparisons for the mean ranks of 'spore' by month are shown in Tables (26-30).

Table 26

Pairwise Comparisons of Spore Mean Ranks: January and February

Comparison	Observed difference	Critical difference
January-February	51.01	65.96
January-April	72.08	72.49
January-May	82.82	70.95
January-June	10.82	83.14
January-July	39.08	76.06
January-August	40.10	62.27
January-September	81.70	68.25
January-October	31.49	78.15
January-November	14.38	76.06
January-December	13.55	58.80
February-May	31.81	82.65
February-September	30.69	80.35
February-December	64.56	72.50

Note. Observed differences greater than critical differences indicate significance at the $p < 0.05$ level.

Table 27

Pairwise Comparisons of Spore Mean Ranks: March

Comparison	Observed difference	Critical difference
March-January	66.41	63.99
March-February	15.40	76.76
March-April	5.67	82.44
March-May	16.41	81.09
March-June	77.23	91.95
March-July	27.33	85.60
March-August	26.31	73.62
March-September	15.29	78.74
March-October	34.92	87.46
March-November	80.80	85.60
March-December	79.97	70.71

Note. Observed differences greater than critical differences indicate significance at the $p < 0.05$ level.

Table 28

Pairwise Comparisons of Spore Mean Ranks: April and June

Comparison	Observed difference	Critical difference
April-February	21.08	83.98
April-May	10.74	87.95
April-June	82.90	98.05
April-July	33.00	92.13
April-August	31.99	81.12
April-September	9.61	85.79
April-October	40.59	93.86
April-November	86.47	92.13
April-December	85.64	78.49
June-February	61.83	93.33
June-May	93.64	96.92
June-July	49.90	100.72
June-August	50.92	90.76
June-September	92.52	94.96
June-October	42.31	102.31
June-November	3.57	100.72
June-December	2.74	88.42

Note. Observed differences greater than critical differences indicate significance at the $p < 0.05$ level.

Table 29

Pairwise Comparisons of Spore Mean Ranks: July to October

Comparison	Observed difference	Critical difference
July-February	11.93	87.08
July-May	43.74	90.92
July-August	1.02	84.32
July-September	42.62	88.83
July-October	7.59	96.64
July-November	53.47	94.96
July-December	52.64	81.80
August-February	10.91	75.34
August-May	42.72	79.74
August-September	41.60	77.35
August-October	8.61	86.21
August-November	54.48	84.32
August-December	53.65	69.16
September-May	1.12	84.49
October-February	19.52	88.91
October-May	51.33	92.67
October-September	50.21	90.62
October-November	45.88	96.64
October-December	45.05	83.74

Note. Observed differences greater than critical differences indicate significance at the $p < 0.05$ level.

Table 30

Pairwise Comparisons of Spore Mean Ranks: November and December

Comparison	Observed difference	Critical difference
November-February	65.39	87.08
November-May	97.21	90.92
November-September	96.08	88.83
November-December	0.83	81.80
December-May	96.38	77.07
December-September	95.25	74.59

Note. Observed differences greater than critical differences indicate significance at the $p < 0.05$ level.

Exploratory-RQ7. Is there an association between the pass-fail assessment and retest?

Exploratory-H_{07}. There is no association between pass-fail and retest.

Exploratory-H_{a7}. There is an association between pass-fail and retest.

A chi-square test of independence was conducted to examine whether 'retest' and 'pass-fail' were independent. There were two levels in pass-fail (1 = pass, 2 = fail) and also two levels in retest (1 = No, 2 = Yes).

The assumption of adequate cell size required that all cells to have expected values greater than zero and 80% of cells to have expected values of at least five (McHugh, 2013). Each of the cells had expected values greater than zero, indicating the first condition was met, and 100% of the cells had expected frequencies of at least five, indicating the second condition was met.

The results of the chi-square test were not significant, $\chi^2(1) = 1.30$, $p = .254$, suggesting that 'retest' and 'pass-fail' were independent of one another. Therefore, the observed frequencies were not significantly different from the expected frequencies (Table 31).

Table 31

Chi-Square Test for Retest and Pass-Fail

	Pass-fail				
Retest	Pass	Fail	χ^2	*df*	*p*
No	170 [172.89]	53 [50.11]	1.30	1	.254
Yes	37 [34.11]	7 [9.89]			

Note. Values formatted as observed [expected].

Exploratory-RQ8. Is there an association between the airborne mold spore count in the work area and retest?

Exploratory-H_{08}. There is no association between spore and retest.

Exploratory-H_{a8}. There is an association between spore and retest.

A two-tailed Mann-Whitney two-sample rank-sum test was conducted to examine whether there were significant differences in 'spore' between the levels of 'retest,' as an alternative to the independent samples *t*-test that did not share the same assumptions (Conover & Iman, 1981). Of the levels of 'retest,' there were 223 observations in the (1 = no) group and 44 observations in the (2 = yes) group.

The results of the two-tailed Mann-Whitney *U* test were not significant, $U = 4418$, $z = -1.04$, $p = .296$, with a mean rank of 131.81 for the (1 = no) group and a mean rank of 145.09 for the (2 = yes) group. The findings suggest that the distribution of 'spore' for the (1 = no) group (*Mdn* = 7.00) was not significantly different from the distribution of 'spore' for the (2 = yes) group (*Mdn* = 8.50). The results of the two-tailed Mann-Whitney *U* test are shown in Table 32 and a boxplot of the ranks of 'spore' by each level of 'retest' is depicted in Figure 10.

Table 32

Two-Tailed Mann-Whitney Test for Spore by Retest

	Mean rank				
Variable	No	Yes	*U*	*z*	*p*
Spore	131.81	145.09	4,418.00	-1.04	.296

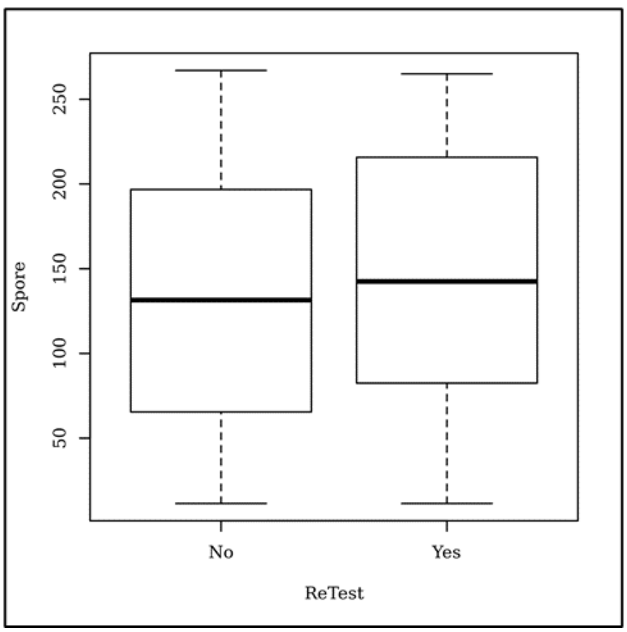

Figure 10. Ranks of spore by retest.

Engineering Controls Analyses

Exploratory-RQ9. Is there a statistically significant relationship between pass-fail and containment?

Exploratory-H$_{09}$. There is no significant relationship between pass-fail and containment.

Exploratory-H$_{a9}$. There is a significant relationship between pass-fail and containment.

A chi-square test of independence was conducted to examine whether ‘pass-fail’ and ‘containment’ were independent. There were two levels in pass-fail (1 = pass, 2 = fail) and four levels in containment (1 = good, 2 = fair, 3 = poor, 4 = none).

The assumption of adequate cell size required all cells to have expected values greater than zero and 80% of cells to have expected values of at least five (McHugh, 2013). Each of the cells showed expected values greater than zero, indicating the first condition was met, although 75% of the cells had expected frequencies of at least five, indicating the second condition was violated. Given one assumption of the chi-square test was violated, a Fisher’s exact test was used to produce more reliable results with small sample sizes, although logit models such as binary logistic regression could have been used but are reserved mostly for larger sample sizes.

The results of the chi-square test were significant, $\chi^2(3) = 26.44$, $p < .001$, suggesting that ‘pass-fail’ and ‘containment’ were dependent. The level combinations of (1 + pass, 2 + pass, 3 + fail, 4 + fail) showed observed values that were greater than the expected values, whereas the combinations of (1 + fail, 2 + fail, 3 + pass, 4 + pass) had observed values that were less than the expected values (Table 33).

Table 33

Chi-Square Test for Containment by Pass-Fail

	Pass-fail				
Containment	Pass	Fail	χ^2	*df*	*p*
1	172 [158.16]	32 [45.84]	26.44	3	< .001
2	7 [6.98]	2 [2.02]			
3	5 [6.20]	3 [1.80]			
4	23 [35.66]	23 [10.34]			

Note. Values formatted as observed [expected].

A Fisher's exact test was conducted to examine whether 'pass-fail' and 'containment' were independent. There were two levels in pass-fail (1 = pass, 2 = fail) and four levels in containment (1 = good, 2 = fair, 3 = poor, 4 = none).

The results of the Fisher's exact test were significant, $p < .001$, suggesting that 'pass-fail' and 'containment' were related to one another. Hence, the null hypothesis was rejected. The level combinations of (1 + pass, 2 + pass, 3 + fail, 4 + fail) showed observed values that were greater than their expected values, whereas the level combinations of (3 + pass, 4 + pass, 1 + fail, 2 + fail) had observed values that were less than the expected values (Table 34).

Table 34

Fisher's Exact Test for Containment and Pass-Fail

	Pass-fail		
Containment	Pass	Fail	*p*
1	172 [158.16]	32 [45.84]	< .001
2	7 [6.98]	2 [2.02]	
3	5 [6.20]	3 [1.80]	
4	23 [35.66]	23 [10.34]	

Note. Values formatted as observed [expected].

Exploratory-RQ10. Is there an association between the airborne spore count in the work area and containment?

Exploratory-H_{010}. There is no association between spore and containment.

Exploratory-H_{a10}. There is an association between spore and containment.

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in 'spore' between the levels of 'containment,' as a non-parametric alternative to the one-way ANOVA that did not share the same distributional assumptions (Conover & Iman, 1981).

The results of the Kruskal-Wallis test were significant, $\chi^2(3) = 34.99$, $p < .001$, indicating that the mean rank of 'spore' was significantly different between the levels of 'containment.' Hence, the null hypothesis was rejected. Table 35 presents the results of the Kruskal-Wallis rank sum test. Figure 11 depicts the boxplots for 'spore' ranked values by 'containment' level.

Table 35

Kruskal-Wallis Rank Sum Test for Spore by Containment

Level	Mean rank	χ^2	*df*	*p*
1	118.88	34.99	3	< .001
2	152.00			
3	193.50			
4	187.17			

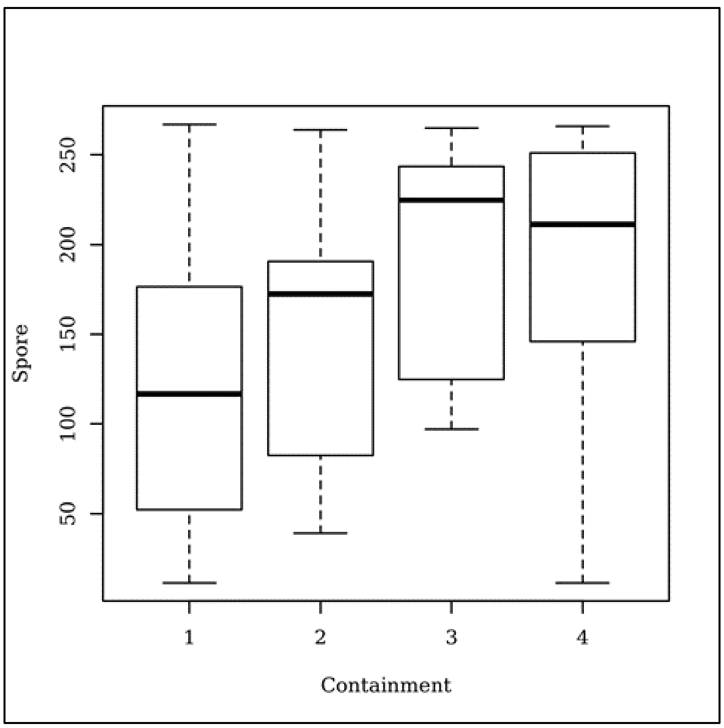

Figure 11. Ranked values of spore by containment level.

Post-hoc pairwise comparisons of spore ranks were examined between each level of ‘containment,’ indicating significant differences between the variable level pairs (1-3, 1-4). The pairwise comparisons are shown in Table 36.

Table 36

Pairwise Comparisons for the Mean Ranks of Spore by Containment Level

Comparison	Observed difference	Critical difference
1-2	33.12	69.39
1-3	74.62	73.43
1-4	68.29	33.25
2-3	41.50	98.99
2-4	35.17	74.26
3-4	6.33	78.04

Note. Observed differences greater than critical differences indicate significance at the $p < 0.05$ level.

Exploratory-RQ11. Is there a statistically significant relationship between pass-fail and decontamination chamber?

Exploratory-H_{011}. There is no significant relationship between pass-fail and decontamination chamber.

Exploratory-H_{a11}. There is a significant relationship between pass-fail and decontamination chamber.

A chi-square test of independence was conducted to examine whether ‘pass-fail’ and ‘decontamination’ chamber were independent. There were two levels in pass-fail (1 = pass, 2 = fail) and two levels in decontamination chamber (1 = no, 2 = yes).

The assumption of adequate cell size was assessed, requiring all cells to have expected values greater than zero and 80% of cells to have expected values of at least five (McHugh, 2013). Each of the cells showed expected values greater than zero, indicating the first condition was met, and 100% of the cells contained expected frequencies of at least five, indicating the second condition was met.

The results of the chi-square test were significant, $\chi^2(1) = 7.27$, $p = .007$, suggesting that 'pass-fail' and 'decontamination' chamber were dependent. Hence, the null hypothesis was rejected. The level combinations of (fail + no, pass + yes) showed observed values that were greater than the expected values, whereas the level combinations of (pass + no and fail + yes) contained observed values that were less than the expected values (Table 37).

Table 37

Chi-Square Test for Pass-Fail by Decontamination Chamber

	Decontamination chamber				
Pass-fail	No	Yes	χ^2	*df*	*p*
Pass	167 [173.39]	39 [32.61]	7.27	1	.007
Fail	51 [44.61]	2 [8.39]			

Note. Values formatted as observed [expected].

Exploratory-RQ12. Is there an association between the airborne mold spore count in the work area and decontamination chamber?

Exploratory-H_{012}. There is no association between spore and decontamination chamber.

Exploratory-H_{a12}. There is an association between spore and decontamination chamber.

A two-tailed Mann-Whitney two-sample rank-sum test was conducted to examine whether there were significant differences in 'spore' between the levels of 'decontamination' chamber, as an alternative to the independent samples *t*-test that did not share the same distributional assumptions (Conover & Iman, 1981). There were 218 observations in the (1 = no) group and 41 observations in the (2 = yes) group.

The results of the two-tailed Mann-Whitney *U* test were significant, $U = 7123.5$, $z = -6.04$, $p < .001$. The mean rank for the (1 = no) group was 142.18 and the mean rank for the (2 = yes) group was 65.26, suggesting that the distribution of 'spore' for the (1 = no) group was significantly different from the distribution of 'spore' for the (2 = yes) group. The median for the (1 = no) group (*Mdn* = 10.00) was significantly larger than the median for the (2 = yes) group (*Mdn* = 1.00). Table 38 presents the results of the two-tailed Mann-Whitney *U* test and Figure 12 depicts a boxplot of the ranks of 'spore' by 'decontamination' chamber.

Table 38

Two-Tailed Mann-Whitney Test for Spore by Decontamination Chamber

	Mean rank				
Variable	No	Yes	*U*	*z*	*p*
Spore	142.18	65.26	7123.50	-6.04	< .001

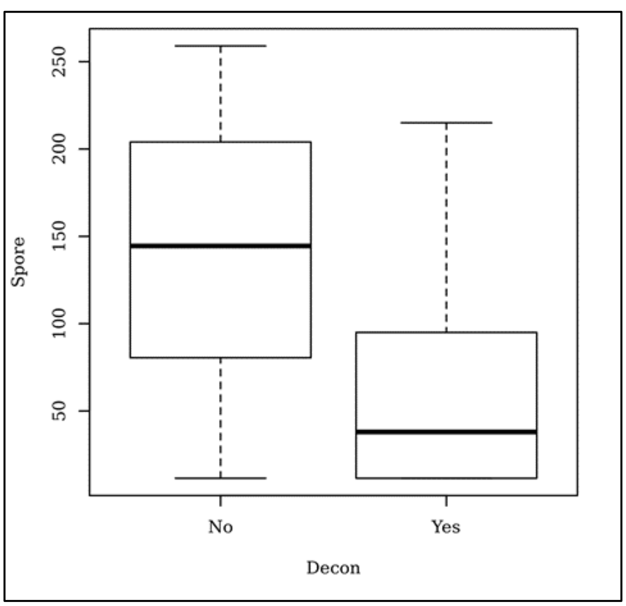

Figure 12. Ranks of spore by decontamination chamber.

Exploratory-RQ13. Is there an association between the airborne mold spore count in the work area and equipment in the work area?

Exploratory-H_{013}. There is no association between spore and equipment.

Exploratory-H_{a13}. There is an association between spore and equipment.

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in 'spore' between the levels of 'equipment,' as a non-parametric alternative to the one-way ANOVA that did not share the same distributional assumptions (Conover & Iman, 1981). There were four levels in the equipment variable (1 = AFD, 2 = AFD + humidifier, 3 = no equipment, 4 = humidifier).

The results of the Kruskal-Wallis test were significant, $\chi^2(3) = 16.90$, $p < .001$, indicating that the mean rank of 'spore' was significantly different between the levels of 'equipment.' The results of the Kruskal-Wallis rank sum test are shown in Table 39 and the boxplots of the ranked values of 'spore' by the levels of 'equipment' are depicted in Figure 13.

Table 39

Kruskal-Wallis Rank Sum Test for Spore by Equipment

Level	Mean rank	χ^2	*df*	*p*
1	121.24	16.90	3	< .001
2	150.21			
3	169.95			
4	238.00			

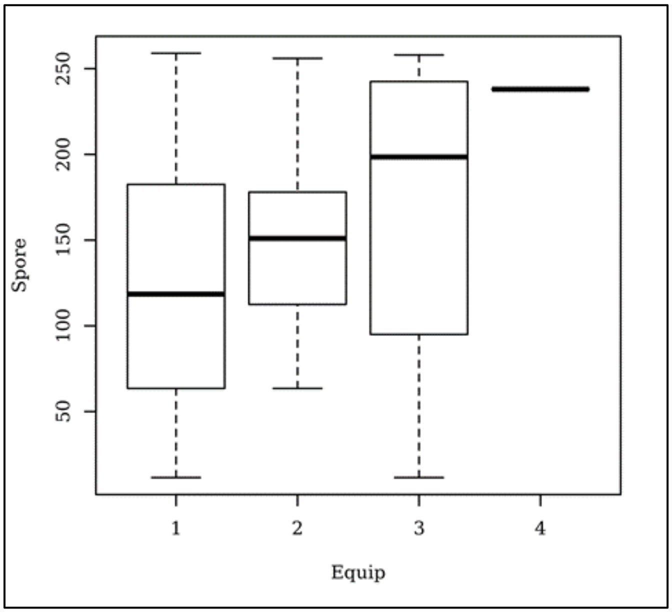

Figure 13. Ranked values of spore by equipment.

Post-hoc pairwise comparisons were examined between each level of ‘equipment,’ indicating significant differences between the (1-3) comparison (Table 40).

Table 40

Pairwise Comparisons for the Mean Ranks of Spore by Equipment

Comparison	Observed difference	Critical difference
1-2	28.97	75.93
1-3	48.71	34.08
1-4	116.76	198.10
2-3	19.74	80.97
2-4	87.79	211.28
3-4	68.05	200.09

Note. Observed differences greater than critical differences indicate significance at the $p < 0.05$ level.

Environmental Condition Analyses

Exploratory-RQ14. Is there an association between the pass-fail assessment and the temperature recorded at the time of assessment?

Exploratory-H$_{014}$. There is no association between pass-fail and temperature.

Exploratory-H$_{a14}$. There is an association between pass-fail and temperature.

A two-tailed Mann-Whitney two-sample rank-sum test was conducted to examine whether there were significant differences in 'temperature' between the levels of 'pass-fail,' as an alternative to the independent samples *t*-test that did not follow the same assumptions (Conover & Iman, 1981). There were 127 observations in the (1 = pass) group and 42 observations in the (2 = fail) group.

The results of the two-tailed Mann-Whitney *U* test were not significant, $U = 2173.5$, $z = -1.80$, $p = .072$. The mean rank for the (1 = pass) group was 81.11 and the mean rank for the (2 = fail) group was 96.75, suggesting that the distribution of 'temperature' for the (1 = pass) group (*Mdn* = 76.00) was not significantly different from the distribution of 'temperature' for the (2 = fail) group (*Mdn* = 80.00). Table 41 shows the results of the two-tailed Mann-Whitney *U* test and Figure 14 presents a boxplot of the ranks of 'temperature' by 'pass-fail.'

Table 41

Two-Tailed Mann-Whitney Test for Temperature by Pass-Fail

	Mean rank				
Variable	Pass	Fail	*U*	*z*	*p*
Temperature	81.11	96.75	2,173.50	-1.80	.072

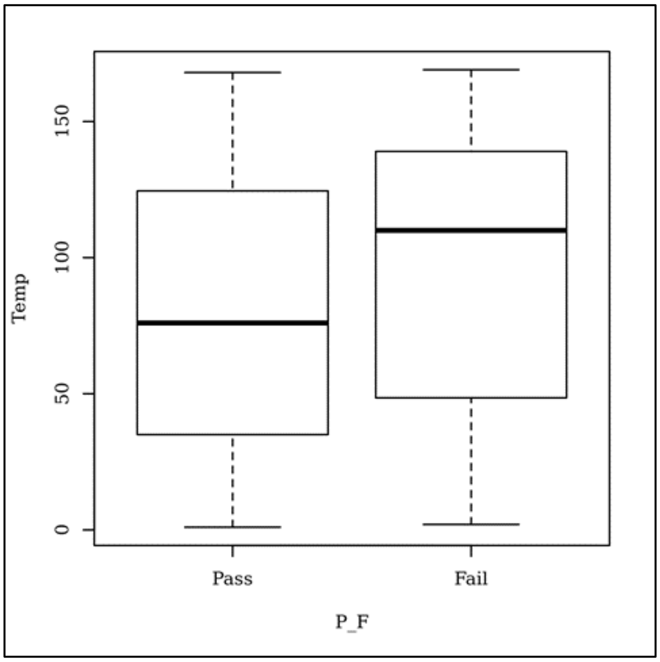

Figure 14. Ranks of temperature by pass-fail.

Exploratory-RQ15. Is there an association between the airborne mold spore count in the work area and the temperature recorded at the time of assessment?

Exploratory-H$_{015}$. There is no association between spore and temperature.

Exploratory-H$_{a15}$. There is an association between spore and temperature.

A Spearman correlation analysis was conducted between ‘spore’ and ‘temperature.’ Cohen’s standard was used to evaluate the strength of the relationship, with coefficients between (0.10 to 0.29) representing small effect sizes, coefficients between (0.30 to 0.49) representing moderate effect sizes, and coefficients above (0.50) indicating large effect sizes (Cohen, 1988). The correlations were not significant between any pairs of the variables (Table 42).

Table 42

Spearman Correlation for Spore and Temperature

Combination	r_s	95% CI *LL*	95% CI *UL*	*p*
Spore-temperature	0.01	-0.14	0.16	.872

Note. CI = confidence interval, *LL* = lower limit, *UL* = upper limit.

Exploratory-RQ16. Is there an association between the pass-fail assessment and the relative humidity recorded at the time of assessment?

Exploratory-H_{016}. There is no association between pass-fail and relative humidity.

Exploratory-H_{a16}. There is an association between pass-fail and relative humidity.

A two-tailed Mann-Whitney two-sample rank-sum test was conducted to examine whether there were significant differences in relative 'humidity' between the levels of 'pass-fail,' as an alternative to the independent samples *t*-test that did not share the same assumptions (Conover & Iman, 1981). There were 127 observations in the (1 = pass) group and 42 observations in the (2 = fail) group.

The results of the two-tailed Mann-Whitney *U* test were not significant, $U = 2672$, $z = -0.02$, $p = .985$. The mean rank for the (1 = pass) group was 85.04 and the mean rank for the (2 = fail) group was 84.88, suggesting that the distribution of relative 'humidity' for the (1 = pass) group (*Mdn* = 45.00) was not significantly different from the distribution of relative 'humidity' for the (2 = fail) group (*Mdn* = 44.00). Table 43 shows the results of the two-tailed Mann-Whitney *U* test and Figure 15 presents a boxplot of the ranks of relative 'humidity' by 'pass-fail.'

Table 43

Two-Tailed Mann-Whitney Test for Relative Humidity by Pass-Fail

	Mean rank				
Variable	Pass	Fail	*U*	*z*	*p*
*Humidity	85.04	84.88	2672.00	-0.02	.985

Note. * = relative.

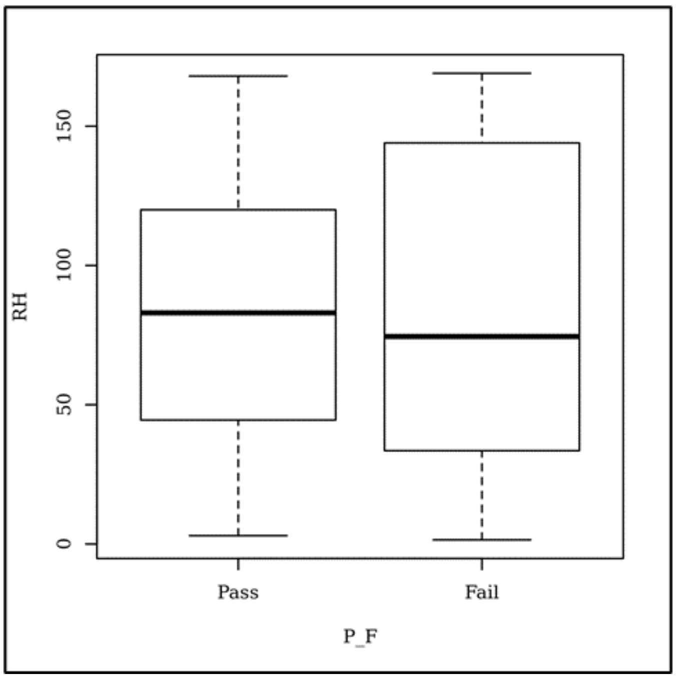

Figure 15. Ranks of relative humidity by pass-fail.

Exploratory-RQ17. Is there an association between the airborne molds count in the work area and the relative humidity recorded at the time of assessment?

Exploratory-H_{017}. There is no association between spore and relative humidity.

Exploratory-H_{a17}. There is an association between spore and relative humidity.

A Spearman correlation analysis was conducted between ‘spore’ and relative ‘humidity.’ Cohen’s standard was used to evaluate the strength of the relationship, with coefficients between

(0.10 to 0.29) representing small effect sizes, coefficients between (0.30 to 0.49) representing moderate effect sizes, and coefficients above (0.50) indicating large effect sizes (Cohen, 1988). There were no significant correlations between any pairs of variables (Table 44).

Table 44

Spearman Correlation for Spore and Relative Humidity

		95% CI		
Combination	r_s	*LL*	*UL*	*p*
Spore-*humidity	0.06	-0.09	0.21	.425

Note. * = relative, CI = confidence interval, *LL* = lower limit, *UL* = upper limit.

Exploratory-RQ18. Is there an association between the pass-fail assessment and affected materials in the work area?

Exploratory-H_{018}. There is no association between pass-fail and affected materials.

Exploratory-H_{a18}. There is an association between pass-fail and affected materials.

A Fisher's exact test was conducted to examine whether 'pass-fail' and 'affect-mat' were independent. There were two levels in pass-fail (1 = pass, 2 = fail) and two levels in affect-mat (1 = no, 2 = yes).

The results of the Fisher's exact test were significant, $p < .001$, suggesting that 'pass-fail' and 'affect-mat' were related to one another. Since the Fisher's exact test was conducted for a two-by-two contingency table, the odds ratio was estimated ($OR = 86.54$), indicating that the odds of observing the (1 = pass) and (1 = no) categories was 86.54 times as likely as observing the (2 = fail) and (1 = no) categories. The level combinations of (pass-no, fail-yes) contained observed values that were greater than the expected values, whereas, the level combinations of (pass-yes, fail-no) showed observed values that were less than the expected values (Table 45).

Table 45

Fisher's Exact Test for Pass-Fail by Affected Materials

	Pass-fail			
Affected materials	Pass	Fail	*OR*	*p*
No	205 [186.71]	37 [48.04]	86.54	< .001
Yes	1 [13.12]	16 [3.37]		

Note. Values formatted as observed [expected], *OR* = odds ratio.

Exploratory-RQ19. Is there an association between the airborne mold spore count in the work area and the affected materials in the work area?

Exploratory-H_{019}. There is no association between spore and affected materials.

Exploratory-H_{a19}. There is an association between spore and affected materials.

A two-tailed Mann-Whitney two-sample rank-sum test was conducted to examine whether there were significant differences in 'spore' between the levels of 'affect-mat,' as an alternative to the independent samples *t*-test that did not share the same assumptions (Conover & Iman, 1981). There were 242 observations in the (1 = no) group and 17 observations in the (2 = yes) group.

The results of the two-tailed Mann-Whitney *U* test were significant, $U = 797$, $z = -4.23$, $p < .001$. The mean rank for the (1 = no) group was 124.79 and the mean rank for the (2 = yes) group was 204.12, suggesting that the distribution of 'spore' for the (1 = no) group was significantly different from the distribution of 'spore' for the (2 = yes) group. The median for the (1 = no) group (*Mdn* = 6.00) was significantly lower than the median for the (2 = yes) group (*Mdn* = 62.00). The results of the two-tailed Mann-Whitney *U* test are shown in Table 46, and a boxplot of the ranks of 'spore' by 'affect-mat' is depicted in Figure 16.

Table 46

Two-Tailed Mann-Whitney Test for Spore by Affected Materials

	Mean rank				
Variable	No	Yes	*U*	*z*	*p*
Spore	124.79	204.12	797.00	-4.23	< .001

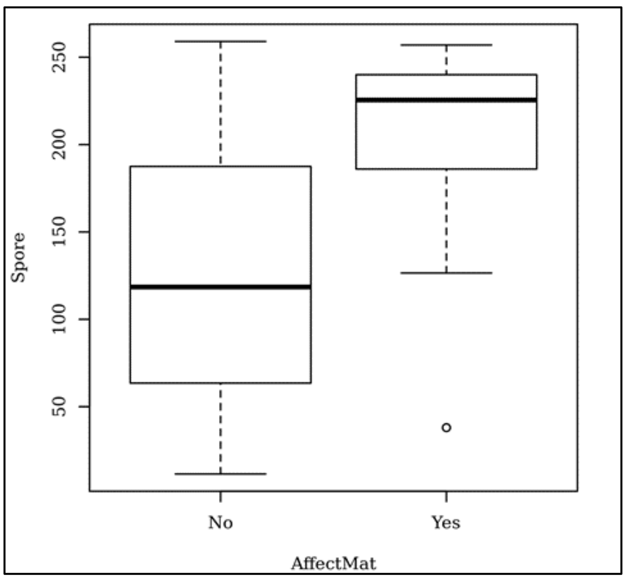

Figure 16. Ranks of spore by affected materials.

Exploratory-RQ20. Is there an association between the pass-fail assessment and damp materials in the work area?

Exploratory-H_{020}. There is no association between pass-fail and damp materials.

Exploratory-H_{a20}. There is an association between pass-fail and damp materials.

A Fisher's exact test was conducted to examine whether 'pass-fail' and 'damp' were independent. There were two levels in pass-fail (1 = pass, 2 = fail) and two levels in damp materials (1 = no, 2 = yes).

The results of the Fisher's exact test were, suggesting that 'pass-fail' and 'damp' were related to one another. Since the Fisher's exact test was conducted for a two-by-two contingency table, the odds ratio was calculated (*OR* = 30.66), indicating that the odds of observing the (1 = pass) and (1= no) categories was 30.66 times as likely as observing the (2 = fail) and (1 = no) categories. The level combinations of (pass-no, fail-yes) contained observed values that were greater than the expected values, whereas the level combinations of (pass-yes, fail-no) showed observed values that were less than the expected values (Table 47).

Table 47

Fisher's Exact Test for Pass-Fail by Damp Materials

	Pass-fail			
Damp	Pass	Fail	*OR*	*p*
No	205 [193.66]	46 [49.82]	30.66	< .001
Yes	1 [6.17]	7 [1.59]		

Note. Values formatted as observed [expected], *OR* = odds ratio.

Exploratory-RQ21. Is there an association between the airborne mold spore count in the work area and the damp materials in the work area?

Exploratory-H_{021}. There is no association between spore and damp materials.

Exploratory-H_{a21}. There is an association between spore and damp materials.

A two-tailed Mann-Whitney two-sample rank-sum test was conducted to examine whether there were significant differences in 'spore' between the levels of 'damp' materials, as an alternative to the independent samples *t*-test that did not share the same assumptions (Conover & Iman, 1981). There were 251 observations in the (1 = no) group and eight observations in the (2 = yes) group.

The results of the two-tailed Mann-Whitney *U* test were significant, $U = 586$, $z = -2.01$, $p = .045$, with a mean rank of 128.33 for the (1 = no) group and a mean rank of 182.25 for the (2 = yes) group. The finding suggests that the distribution of 'spore' for the (1 = no) group was significantly different from the distribution of 'spore' for the (2 = yes) group. The median for the (1 = no) group (*Mdn* = 7.00) was significantly lower than the median for the (2 = yes) group (*Mdn* = 41.50). Table 48 shows the results of the two-tailed Mann-Whitney *U* test, and Figure 17 presents a boxplot of the ranks of 'spore' by 'damp' materials.

Table 48

Two-Tailed Mann-Whitney Test for Spore by Damp Materials

	Mean rank				
Variable	No	Yes	*U*	*z*	*p*
Spore	128.33	182.25	586.00	-2.01	.045

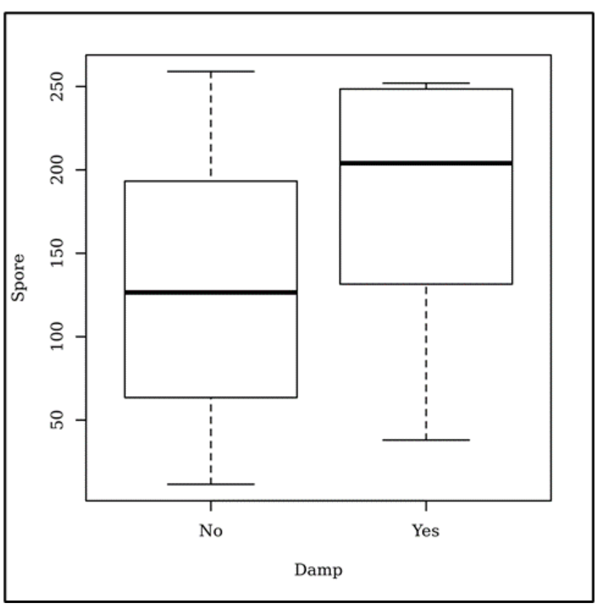

Figure 17. Ranks of spore by damp materials.

Exploratory-RQ22. Is there an association between the pass-fail assessment and mold stachybotrys identified in the air sample collected in the work area?

Exploratory-H_{022}. There is no association between pass-fail and mold stachybotrys.

Exploratory-H_{a22}. There is an association between pass-fail and mold stachybotrys.

A chi-square test of independence was conducted to examine whether 'pass-fail' and 'mold-stachy' were independent. There were two levels in pass-fail (1 = pass, 2 = fail) and two levels in mold-stachy (1 = no, 2 = yes).

The assumption of adequate cell size was assessed, requiring all cells to have expected values greater than zero and 80% of cells to have expected values of at least five (McHugh, 2013). Each of the cells had expected values greater than zero, indicating the first condition was met, and 100% of the cells had expected frequencies of at least five, indicating the second condition was met.

The results of the Chi-square test were significant, $\chi^2(1) = 69.10$, $p < .001$, suggesting that 'pass-fail' and 'mold-stachy' were dependent. The level combinations of (pass-no, fail-yes) contained observed values that were greater than the expected values, whereas the level combinations of (fail-no, pass-yes) contained observed values that were less than the expected values (Table 49).

Table 49

Chi-Square Test for Mold Stachybotrys by Pass-Fail

	Mold-stachy				
Pass-fail	No	Yes	χ^2	*df*	*p*
Pass	199 [179.87]	8 [27.13]	69.10	1	< .001
Fail	33 [52.13]	27 [7.87]			

Note. Values formatted as observed [expected].

A Fisher's exact test was conducted to examine whether 'pass-fail' and 'mold-stachy' were independent. There were two levels in pass-fail (1 = pass, 2 = fail) and two levels in mold-stachy (1 = no, 2 = yes).

The results of the Fisher's exact test were significant, $p < .001$, suggesting that 'pass-fail' and 'mold-stachy' were related to one another. Since the Fisher's exact test was conducted for a two-by-two contingency table, the odds ratio was calculated ($OR = 19.98$), indicating that the odds of observing the (1 = pass, 1 = no) categories was 19.98 times as likely as observing the (2 = fail, 1 = no) categories. The level combinations of (pass-no, fail-yes) contained observed values that were greater than the expected values, whereas the level combinations of (pass-yes, fail-no) showed observed values that were less than the expected values (Table 50).

Table 50

Fisher's Exact Test of Mold Stachybotrys by Pass-Fail

	Pass-fail			
Mold-stachy	Pass	Fail	*OR*	*p*
No	199 [179.87]	33 [52.13]	19.98	< .001
Yes	8 [27.13]	27 [7.87]		

Note. Values formatted as observed [expected], *OR* = odds ratio.

Exploratory-RQ23. Is there an association between the airborne mold spore count in the work area and mold stachybotrys identified in the air sample collected in the work area?

Exploratory-H_{023}. There is no association between spore and mold stachybotrys.

Exploratory-H_{a23}. There is an association between spore and mold stachybotrys.

A two-tailed Mann-Whitney two-sample rank-sum test was conducted to examine whether there were significant differences in 'spore' between the levels of 'mold-stachy,' as an alternative to the independent samples *t*-test that did not share the same assumptions (Conover & Iman, 1981). There were 232 observations in the (1 = no) group and 35 observations in the (2 = yes) group.

The results of the two-tailed Mann-Whitney *U* test were significant, $U = 2289.5$, $z = -4.16$, $p < .001$, with a mean rank of 126.37 for the (1 = no) group and mean rank of 184.59 for the (2 = yes) group. The finding suggests that the distribution of 'spore' for the (1 = no) group was significantly different from the distribution of 'spore' for the (2 = yes) group. The median for the (1 = no) group (*Mdn* = 6.00) was significantly lower than the median for 2 = yes) group (*Mdn* = 28.00). Table 51 shows the results of the two-tailed Mann-Whitney *U* test, and Figure 18 depicts a boxplot of the ranks of 'spore' by 'mold-stachy.'

Table 51

Two-Tailed Mann-Whitney Test for Spore by Mold Stachybotrys

	Mean rank				
Variable	No	Yes	*U*	*z*	*p*
Spore	126.37	184.59	2289.50	-4.16	< .001

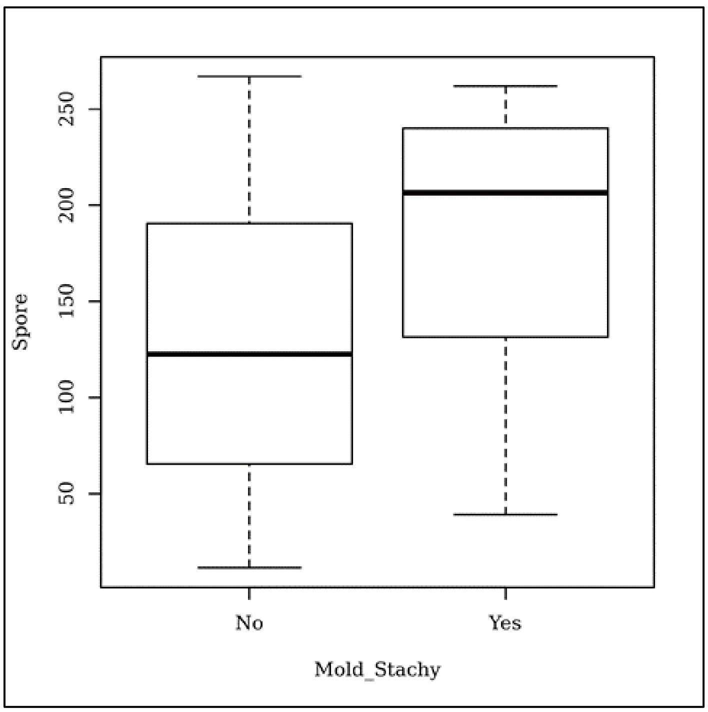

Figure 18. Ranks of spore by mold Stachybotrys.

Exploratory-RQ24. Is there an association between the pass-fail assessment and airborne mold spore count in the non-affected area?

Exploratory-H$_{024}$. There is no association between pass-fail and non-affected area spore count.

Exploratory-H$_{a24}$. There is an association between pass-fail and non-affected area spore count.

A two-tailed Mann-Whitney two-sample rank-sum test was conducted to examine whether there were significant differences in 'NAA-spore' levels between the levels of 'pass-fail,' as an alternative to the independent samples *t*-test but does not share the same assumptions (Conover & Iman, 1981). There were 134 observations in the (1 = pass) group and 34 observations in the (2 = fail) group.

The results of the two-tailed Mann-Whitney *U* test were significant, $U = 1672$, $z = -2.39$, $p = .017$, with a mean rank of 78.98 for the (1 = pass) group and mean rank of 102.32 for the (2 = fail) group. The findings suggest that the distribution of 'NAA-spore' for the (1 = pass) group was significantly different from the distribution of 'NAA-spore' for the (2 = fail) group. The median for the (1 = pass) group (*Mdn* = 20.00) was significantly lower than the median for the (2 = fail) group (*Mdn* = 30.00). Table 52 shows the results of the two-tailed Mann-Whitney *U* test, and Figure 19 depicts a boxplot of the ranks of 'NAA-spore' by 'pass-fail.'

Table 52

Two-Tailed Mann-Whitney Test for Non-Affected Area Spore by Pass-Fail

	Mean rank				
Variable	Pass	Fail	*U*	*z*	*p*
NAA-spore	79.98	102.32	1672.00	-2.39	.017

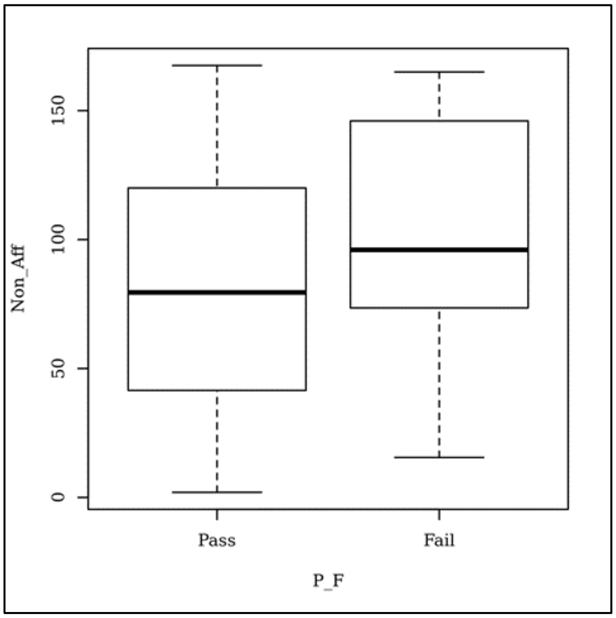

Figure 19. Ranks of non-affected area spore by pass-fail.

Exploratory-RQ25. Is there an association between the airborne mold spore count in the work area and airborne mold spore count in the non-affected area?

Exploratory-H$_{024}$. There is no association between spore in the work area and non-affected area spore.

Exploratory-H$_{a24}$. There is an association between spore in the work area and non-affected area spore.

A Spearman correlation analysis was conducted between 'spore' and 'NAA-spore.' Cohen's standard was used to evaluate the strength of the relationship, with coefficients between (0.10 to 0.29) representing small effect sizes, coefficients between (0.30 to 0.49) representing moderate effect sizes, and coefficients above (0.50) indicating large effect sizes (Cohen, 1988).

A significant positive correlation, $r_s = 0.58$, $p < .001$, was observed between 'spore' and ''NAA-spore,' showing a large effect size. The correlation indicates that as work area 'spore' increases, 'NAA-spore' tends to increase (Table 53).

Table 53

Spearman Correlation for Spore and Non-Affected Area Spore

		95% CI		
Combination	r_s	*LL*	*UL*	*p*
Spore-NAA-spore	0.58	0.47	0.67	< .001

Note. CI = confidence interval, *LL* = lower limit, *UL* = upper limit, NAA = non-affected area.

Exploratory-RQ26. Is there an association between the pass-fail assessment and airborne mold spore count outside?

Exploratory-H_{026}. There is no association between pass-fail and outside spore.

Exploratory-H_{a26}. There is an association between pass-fail and outside spore.

A two-tailed Mann-Whitney two-sample rank-sum test was conducted to examine whether there were significant differences in 'outside-spore' between the levels of 'pass-fail,' as an alternative to the independent samples *t*-test that did not share the same assumptions (Conover & Iman, 1981). There were 206 observations in the (1 = pass) group and 58 observations in the (2 = fail) group.

The results of the two-tailed Mann-Whitney *U* test were significant, $U = 4751.5$, $z = -2.38$, $p = .017$, with a mean rank of 126.57 for the (1 = pass) group and mean rank of 153.58 for the (2 = fail) group. The finding suggests that the distribution of 'outside-spore' for the (1 = pass) group was significantly different from the distribution of 'outside-spore' for the (2 = fail) group. The median for the (1 = pass) group (*Mdn* = 49.00) was significantly lower than the median for the (2 = fail) group (*Mdn* = 67.00). Table 54 presents the results of the two-tailed Mann-Whitney *U* test, and Figure 20 presents a boxplot of the ranks of 'outside-spore' by 'pass-fail.'

Table 54

Two-Tailed Mann-Whitney Test for Outside-Spore by Pass-Fail

	Mean rank				
Variable	Pass	Fail	*U*	*z*	*p*
Outside-spore	126.57	153.58	4751.50	-2.38	.017

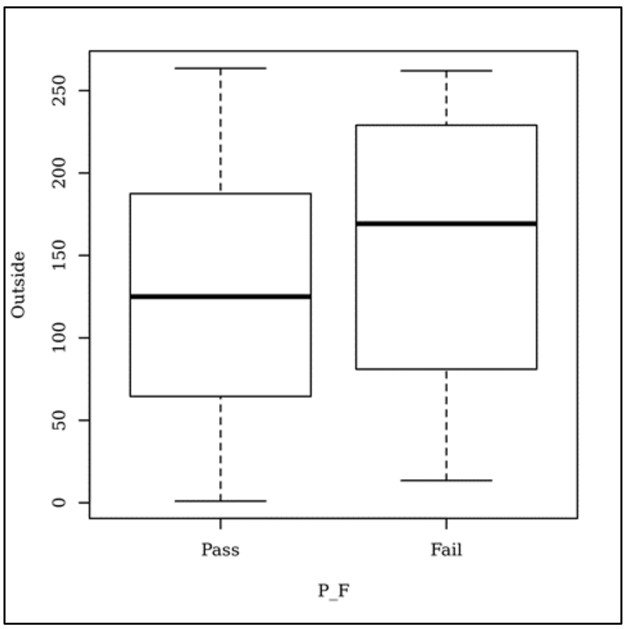

Figure 20. Ranks of outside-spore by pass-fail.

Exploratory-RQ27. Is there an association between the airborne spore count in the work area and spore count outside?

Exploratory-H_{027}. There is no association between spore and outside spore.

Exploratory-H_{a27}. There is an association between spore and outside spore.

A Spearman correlation analysis was conducted between ‘spore’ and ‘outside-spore.’ Cohen’s standard was used to evaluate the strength of the relationship, with coefficients between

(0.10 to 0.29) representing small effect sizes, coefficients between (0.30 to 0.49) representing moderate effect sizes, and coefficients above (0.50) indicating large effect sizes (Cohen, 1988).

A significant positive correlation, $r_s = 0.24$, $p < .001$, was observed between 'spore' and 'outside-spore,' showing a small effect size. The correlation indicates that as 'spore' increases, 'outside-spore' tends to increase (Table 55).

Table 55

Spearman Correlation for Spore and Outside Spore

		95% CI		
Combination	r_s	*LL*	*UL*	*p*
Spore-outside-spore	0.24	0.12	0.35	< .001

Note. CI = confidence interval, *LL* = lower limit, *UL* = upper limit.

Exploratory-RQ28. Is there an association between the pass-fail assessment and hyphae count identified in the work area air sample?

Exploratory-H$_{028}$. There is no association between pass-fail and hyphae.

Exploratory-Ha28. There is an association between pass-fail and hyphae side.

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in 'hyphae' between the levels of 'pass-fail,' as a non-parametric alternative to the one-way ANOVA that did not share the same distributional assumptions (Conover & Iman, 1981).

The results of the Kruskal-Wallis test were significant, $\chi^2(1) = 23.64$, $p < .001$, indicating that the mean rank of 'hyphae' was significantly different between the levels of 'pass-fail.' (Table 56). Boxplots of the ranked values of 'hyphae' by the levels of 'pass-fail' are shown in Figure 21.

Table 56

Kruskal-Wallis Rank Sum Test for Hyphae by Pass-Fail

Level	Mean rank	χ^2	*df*	*p*
Pass	100.90	23.64	1	< .001
Fail	147.29			

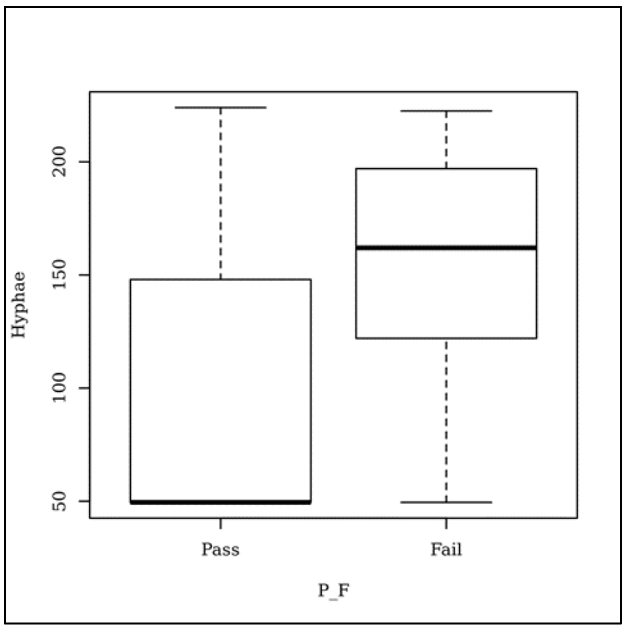

Figure 21. Ranked values of hyphae by the levels of pass-fail.

Pairwise comparisons were examined between each level of 'pass-fail,' indicating significant differences between the two levels of 'pass-fail' (Table 57).

Table 57

Pairwise Comparisons for the Mean Ranks of Hyphae by Levels of Pass-Fail

Comparison	Observed difference	Critical difference
Pass-fail	46.39	19.60

Note. Observed differences greater than critical differences indicate significance at the $p < 0.05$ level.

A two-tailed Mann-Whitney two-sample rank-sum test was conducted to examine whether there were significant differences in 'hyphae' between the levels of 'pass-fail,' as an alternative to the independent samples *t*-test that did not share the same assumptions (Conover & Iman, 1981). There were 168 observations in the (1 = pass) group and 56 observations in the (2 = fail) group.

The results of the two-tailed Mann-Whitney *U* test were significant, $U = 2,755.5$, $z = -4.86$, $p < .001$, with a mean rank of 100.90 for the (1 = pass) group and mean rank of 147.29 for the (2 = fail) group. The findings suggest that the distribution of 'hyphae' for the (1 = pass) group was significantly different from the distribution of 'hyphae' for the (2 = fail) group. The median for the (1 = pass) group (*Mdn* = 0.00) was significantly lower than the median for the (2 = fail) group (*Mdn* = 39.00). Table 58 presents the results of the two-tailed Mann-Whitney *U* test, and Figure 22 presents a boxplot of the ranks of 'hyphae' by 'pass-fail.'

Table 58

Two-Tailed Mann-Whitney Test for Hyphae by Pass-Fail

	Mean rank				
Variable	Pass	Fail	*U*	*z*	*p*
Hyphae	100.90	147.29	2755.50	-4.86	< .001

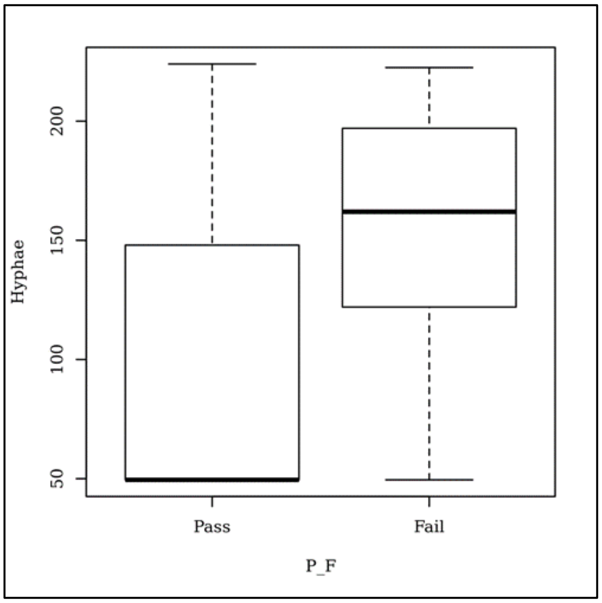

Figure 22. Ranks of hyphae by pass-fail.

Exploratory-RQ29. Is there an association between spore and hyphae count identified in the work area air sample**?**

Exploratory-H$_{029}$. There is no association between spore and hyphae.

Exploratory-H$_{a29}$. There is an association between spore and hyphae.

A Spearman correlation analysis was conducted between 'spore' and 'hyphae,' using Cohen's standard to evaluate the strength of the relationship, with coefficients between (0.10 to 0.29) representing small effect sizes, coefficients between (0.30 to 0.49) representing moderate effect sizes, and coefficients above (0.50) indicating large effect sizes (Cohen, 1988).

A significant positive correlation, $r_s = 0.57$, $p < .001$, was observed between 'spore' and 'hyphae,' showing a large effect size (Table 59). The correlation indicates that as 'spore' increases, 'hyphae' tends to increase.

Table 59

Spearman Correlation for Spore and Hyphae

Combination	r_s	95% CI Lower	95% CI Upper	p
Spore-hyphae	0.57	0.47	0.65	< .001

Note. CI = confidence interval, *LL* = lower limit, *UL* = upper limit.

Exploratory-RQ30. Is there an association between the pass-fail assessment and the level of background debris identified in the work area air sample?

H_{030}. There is no association between pass-fail and debris.

H_{a30}. There is an association between pass-fail and debris.

A Kruskal-Wallis rank sum test was conducted to assess if there were significant differences in 'spore' between the levels of 'debris,' as a non-parametric alternative to the one-way ANOVA that did not have the same distributional assumptions (Conover & Iman, 1981).

The results of the Kruskal-Wallis test were significant, $\chi^2(7) = 92.93$, $p < .001$, indicating that the mean rank of 'spore' was significantly different between the levels of 'debris' (Table 60). Figure 23 presents the boxplots of ranked values of 'spore' by the levels of 'debris.'

Table 60

Kruskal-Wallis Rank Sum Test for Spore by Debris

Level	Mean rank	χ^2	*df*	*p*
1	49.39			
1+	30.44			
2	94.06			
2+	73.18			
3	163.93	92.93	7	< .001
3+	139.07			
4	144.25			
4+	136.75			

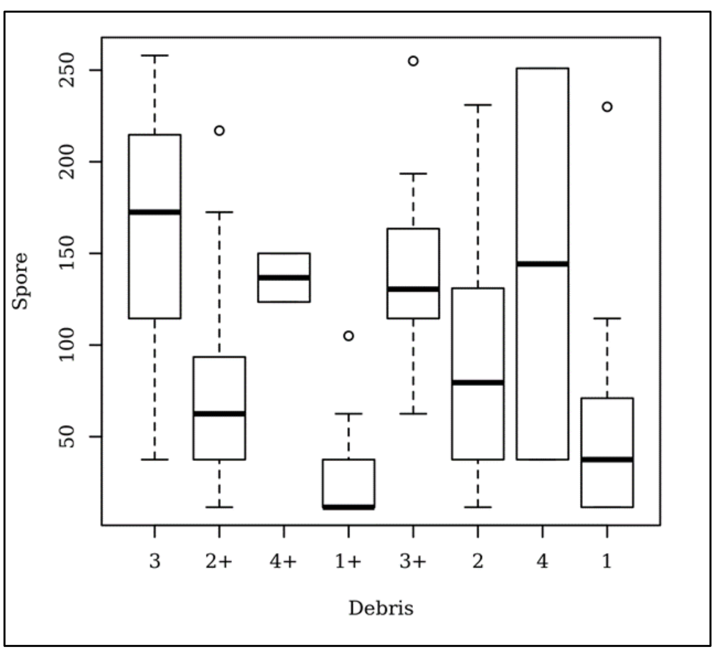

Figure 23. Ranked values of spore by the levels of debris.

Post-hoc pairwise comparisons were examined between each level of 'debris.' The results of the multiple comparisons indicated significant differences between the variable pairs (3-2+, 3-1+, 3-2, 3-1, 1+-3+, a 3+-1). Table 61 and Table 62 show the results of the pairwise comparisons.

Table 61

Pairwise Comparisons for the Mean Ranks of Spore by Levels of Debris

Comparison	Observed difference	Critical difference
3-2+	90.75	50.43
3-4+	27.18	165.94
3-1+	133.48	80.04
3-3+	24.86	65.20
3-2	69.87	41.57
3-4	19.68	165.94
3-1	114.53	56.83
2+-4+	63.57	171.29
2+-1+	42.74	90.61
2+-3+	65.89	77.81
2+-2	20.88	59.43
2+-4	71.07	171.29
2+-1	23.79	70.95
4+-1+	106.31	182.22
4+-3+	2.32	176.21

Note. Observed differences greater than the critical differences indicate significance at the $p < 0.05$ level.

Table 62

Pairwise Comparisons for the Mean Ranks of Spore by Levels of Debris

Comparison	Observed difference	Critical difference
4+-2	42.69	168.90
4+-4	7.50	233.10
4+-1	87.36	173.29
1+-3+	108.63	99.59
1+-2	63.62	86.00
1+-4	113.81	182.22
1+-1	18.95	94.32
3+-2	45.01	72.38
3+-4	5.18	176.21
3+-1	89.68	82.10
2-4	50.19	168.90
2-1	44.67	64.95
4-1	94.86	173.29

Note. Observed differences greater than the critical differences indicate significance at the $p < 0.05$ level.

Evaluation of Findings

The statistical analyses identified a correlation between the pass-fail grade assigned by the IEP and the total spore count result from air testing in the affected area, which suggests that projects with fewer spores in the work area are more likely to pass PRV. The outcome of a remediation project was defined by two variables: the evaluation by the IEP as pass-fail and the total airborne spore count, a quantitative measure, in the work area. The spore result was a part of the consideration for the IEP evaluation and determination of the project outcome as successful (pass) or not (fail). The two variables, IEP pass-fail assessment and total airborne spore count, were found to be related in this study.

There was a correlation between how work was performed and the pass-fail grade assigned by the IEP. The strongest associations with failing the IEP assessment were work that did not follow consensus documents and work that partially followed consensus documents. The results of the analysis imply that remediation contractors who do not follow consensus document recommended work practices are more likely to fail the IEP evaluation. Furthermore, the results showed that partially following consensus document recommendations was strongly associated with a failed project assessment. Taken together, the major implication is that following consensus document guidelines will more often result in project success as defined by a passing IEP assessment.

There was a correlation between the total spore count in the affected area and how work was performed. In addition, there was an association between following consensus document guidelines and a lower mean rank for spores, with fewer spores in the work area more likely to result in a passing assessment, whereas not following or partially following the recommended consensus document guidelines for work were more likely to result in a failing assessment. Moreover, a positive association was found between the pass-fail assessment and the overall model of work, contractor, and containment, although the association between the pass-fail assessment and work was not significant when the effect of contractor and containment were adjusted in the analysis. As such, this implies that the presence or condition of a containment and the type of contractor did not significantly affect the odds of failing the assessment when the remediation work followed or partially followed the consensus document guidelines.

An overall positive association was found between the IEP pass-fail grade and the type of contractor, and between the levels of pass-fail and levels of contractor type, the strongest associations were between passing and remediator, failing and general contractor, and failing and handyman or maintenance worker. There was also a positive association between spore and contractor, significant differences in the mean of spore for each of the three levels of contractor type, and pairwise significance differences between the contractor levels of remediator and general contractor, and remediator and handyman or maintenance worker. Therefore, these findings imply that contractor type, particularly a remediator, is more likely to pass the IEP assessment compared to general contractors and handymen or maintenance workers.

A significant negative correlation with a small effect size was found between spore and age, showing that as spore count increases, age tends to decrease, which implies that older homes are more likely to have more spores than newer homes. Additionally, a statistically significant relationship between spore and month of assessment, and a correlation between pass-fail and the month of the assessment, were found. Since, the assessments completed in January, February, March, October, November, and December were more likely to pass, and the assessments completed in April, May, June, July, August, and September were more likely to fail, this implies that the passing months and failing months may share some degree of a common seasonal factor underlying the differences in the results of the pass-fail assessment. Further, there was no significant correlations between spore and retest, or pass-fail and retest that were found in the analysis.

The levels of the pass-fail assessment and containment were positively associated, with the strongest associations between pass and containment in good condition, passing and containment in fair condition, fail and containment in poor condition, and fail and containment absent. In addition, spore and containment were positively associated, with statistically significant differences in average spore count across each of the four levels of containment, and significance differences in average spore count between the pairwise comparisons of good and poor, and good and no containment. There was also a positive association between pass-fail and decontamination chamber, with the strongest association between fail and no decontamination chamber. Spore and decontamination chamber were associated, and the average spore count was significantly higher for no decontamination chamber, indicating that spore count in the work area was higher when a decontamination chamber was not used.

There were significant differences in spore between the levels of equipment. The average spore count was the lowest when an air filtration device was used, higher when an air filtration device and dehumidifier were used, still higher when no equipment was used, and the highest when only a dehumidifier was used. There was no significant correlation between spore and temperature, and similarly, no significant correlation between pass-fail and temperature found in the analyses. Moreover, there was no significant correlation between spore and relative humidity and no significant correlation between pass-fail and relative humidity observed in the analyses. However, there was a statistically significant relationship between spore and affected materials. The mean rank for spore was significantly lower when no affected materials were present. Similarly, there was a significant relationship between pass-fail and affected materials, in which the odds of passing the pass-fail assessment were 86.54 times more likely when no affected materials were present. Like the significant relationship among pass-fail and affected materials, there was also is a statistically significant relationship between spore and damp materials, with a mean rank for spore was significantly lower when no damp materials were present. Furthermore, there was a significant relationship between pass-fail and damp materials, in which the odds of passing the pass-fail assessment were 30.66 times more likely when no damp materials were present.

The relationship between spore and mold-stachybotrys was found to be significant, with a mean rank for spore that was significantly lower when no mold-stachybotrys was present. The relationship between pass-fail and mold-stachybotrys was also found to be significant, in which the odds of passing the pass-fail assessment were 19.98 times more likely when no mold-stachybotrys was present compared to failing the pass-fail assessment with no mold-stachybotrys. A significant positive correlation with a large effect size was also found between spore and non-affected area spore, showing that as spore increased, non-affected area spore tended to increase. In addition, a significant relationship between pass-fail and non-affected area spore was found, with a median for a pass on the pass-fail assessment that was significantly lower than the median for fail on the pass-fail assessment. Furthermore, a significant positive correlation of small effect size was found between spore and outside-spore, illustrating that as spore increased, outside-spore tended to increase. Moreover, a significant relationship was observed between pass-fail and the outside-spore count, with a median for a pass on the pass-fail assessment that was significantly lower than the median for fail on the pass-fail assessment.

A significant positive correlation with a large effect size was found between spore and hyphae, showing that as spore increased, hyphae tended to increase. There was also a statistically significant relationship between pass-fail and hyphae, with a mean for a pass on the pass-fail assessment that was significantly lower than the mean for fail on the pass-fail assessment. Additionally, a statistically significant association was observed between spore and the different levels of debris, with a mean rank for spore that was lowest at the lowermost rank of debris. The mean rank for spore began to decrease when background levels of debris increased for the average ranking above level (3), whereas the highest mean rank of spore at debris level (4+) was lower than the middle ranking. Altogether, the higher rankings of debris increased the likelihood that spore was under-represented (EMSL, 2011).

Summary

The univariate, bivariate, and multivariate analysis of Chapter IV was conducted to examine the relationship between how water damage mitigation and mold remediation work was performed and the project outcome as evaluated by the IEP report and raw airborne mold spore count in the work area. A dataset was created from project reports, job notes, photographs, and laboratory reports of IEP reports collected in the form of a survey and digital files containing project information and since no centralized data existed. Initial univariate distributional tests showed skewed distributions for several variables, non-parametric statistical tests were used when the a priori statistical tests could not be performed. The bivariate and multivariate analysis revealed several significant associations and correlations that supported mold remediation work that follows consensus guidelines. Several exploratory research questions and hypotheses were developed a posteriori in the execution of the analysis organized around project characteristics, engineering controls, and environmental conditions after noticing common factors involved with the success or failure of the IEP assessment. The exploratory analysis helped to paint a more robust picture of the factors that influence the outcomes of IEP assessments. Altogether, the results of the main analysis and exploratory analysis led to several implications that may benefit future research outlined in Chapter V.

Chapter Five: Discussion and Conclusions

Damp and moldy living environments carry certain health risks to building occupants, and it is well-established that occupants and also workers are exposed to airborne mold spores anytime building materials are disturbed after water damage and mold occur (CDC, 2017; EPA, 1989; IOM, 2004; Johanning et al., 2014; NIOSH, 2013; WHO-EUR, 2009). To address this issue, consensus documents were devised that recommend the use of an IEP for post-remediation verification and clearance testing to ensure mold spore exposure is limited, and it is assumed that the testing and assessments of IEPs accurately evaluate the physical and environmental condition of the work area through moisture assessment, visual assessment, and testing for airborne mold spores (IICRC S520, 2015b). Two primary consensus documents exist to provide guidance and recommendations for training, work procedures, engineering controls, and follow-up assessments. As such, the problem addressed by the dissertation research was the failure of the construction industry as a whole to embrace standard mold remediation protocols and methods thought to reduce airborne mold spores resulting from water damage mitigation and mold remediation activities, and subsequently worker and occupant exposure. Therefore, the primary purpose of the research was to validate the consensus guideline document work practices for water damage mitigation, mold remediation, and successful project outcomes through rigorous statistical analysis. A quantitative, nonexperimental correlational design using secondary data and survey data was selected as the ideal approach to determine whether contractor work that followed the consensus guideline recommendations resulted in lower mold spore count and successful post-remediation verification testing. The analysis of each null hypothesis showed:

1. A significant and almost doubled mean rank of airborne mold spore count in the work area in the fail group of the pass-fail assessment compared to the pass-group.

2. The mean rank of airborne mold spore count in work that did not follow consensus guidelines was significantly the highest of all work types and higher than the work that partially followed consensus guidelines, whereas the mean rank of airborne mold spore count in work that followed consensus guidelines was significantly the lowest of all work types and nearly half of the estimate for work that did not follow consensus guidelines.
3. A significant association between the pass-fail assessment and work that did not, partially, and did follow consensus guidelines, showing that work that did not or only partially followed consensus guidelines were more likely to fail the assessment, whereas work that followed consensus guidelines were more likely to pass the assessment.
4. A significant and positive association between the pass-fail assessment and the overall model of work, contractor, and containment, although the association between the pass-fail assessment and work was not significant when the effect of contractor and containment were adjusted in the analysis.

Although the analysis revealed evidence showing the use of consensus guidelines increased the propensity for passing the pass-fail assessment and lower mold spore counts, there were key limitations of the research and findings. First, the use of a non-experimental correlational design does not permit a cause-and-effect interpretation due to lack of random sampling, random allocation to an experimental condition, and temporal sequence. Second, since the data used for analysis was collected by a survey instrument based on IEP reports that included a subjective decision by each IEP to pass or fail remediation work in the pass-fail assessment and each IEP used unique criteria to make the pass-fail decision, bias among IEPs in the pass-fail decision could not be ruled out. Lastly, several confounding factors including: (a) failing the assessment for elevated moisture from building materials even with an acceptable sport count in the work area, (b) previous containment construction, unknown containment construction, impractical containment openings for large appliances or bulky building materials, (c) contractor work practices that did not allow for confirmation of following consensus guidelines, (d) type of construction, and (e) the use of the raw count of mold spores instead of other spore measures, were identified but could not be adjusted in the analyses. Given the problem and purpose of the study, the design, results, and limitations, Chapter V examines the implications of the research findings to the literature and practice in the field, and details recommendations for future research.

Implications

RQ1-The association between pass-fail and spore count in the work area. It was first important to determine if there was an association between the pass or fail grade assigned to the project by the IEP and the total spore count in the work area. Bivariate analysis by the Mann-Whitney *U* Test yielded a significant correlation between the total spore count in the work area and the pass or fail grade assigned by the IEP. Projects with fewer spores in the work area were more likely to pass an IEP assessment. Given there are no established exposure limits for sport count and type, and because of this, each IEP does not use the spore count alone for an assessment, other associations were explored in the dissertation research.

RQ2-The association between work and spore count in the work area. The relationship between how closely the work followed consensus document guidelines and the total spore count in the work area was important. Work was broken down to levels that described how the mitigation or remediation work was performed. The work either did not follow consensus document recommendations, partially followed consensus document recommendations, or did follow consensus document recommendations. The work that followed consensus document recommendations was expected to result in fewer spores in the work area. Multivariate analyses using the Kruskal-Wallis Test showed that there was a correlation between the spore count in the work area and how the work was performed. The mean rank for spore was the highest for work that did not follow consensus document guidelines, whereas the mean rank for spore was lower for work that partially followed consensus document guidelines and lowest for work that did follow consensus document guidelines. Post-hoc pairwise comparisons revealed the most observed difference occurred between work that did not follow consensus document guidelines and work that did follow consensus document guidelines. Taken together, these findings imply that work following consensus document guidelines resulted in few spores in the work area and validate recommendations for work to follow consensus document guidelines, given a relationship between the work and a lower spore count in the work area was established.

RQ3-The association between work and the pass-fail by the IEP. Bivariate analyses between how closely the work followed consensus document guidelines and the pass-fail by the IEP revealed significant associations. The strongest associations for failing were work that did not follow consensus document guidelines and work that partially followed consensus document guidelines. The bivariate findings revealed important associations that suggest the use of consensus document guidelines more often resulted in a passing project as evaluated by the IEP.

The benefits of following consensus document recommendations. An IEP assesses a project both quantitatively (total spore count in the work area) and subjectively (pass-fail grade and evaluation of the work). There were significant associations established between the total spore count in the work area and how the work was performed, which provides evidence that implies following the consensus documents recommendations more likely results in successful projects that pass an IEP assessment with fewer mold spores remaining in the work area. From this implication, two important areas are largely impacted by the field practice of mold remediation projects. First, a successful project will have few spores and no remaining affected or damp materials more often if consensus guidelines are followed, which means that poor health outcomes and risks to building occupants are likely reduced given that the indoor environment is not damp or moldy. Second, the potential reduction in respiratory illness related to occupying damp and moldy spaces may have a substantial and positive effect on health burden. As a whole, financial beneficiaries of ensuring work follows consensus guidelines are building occupants, health insurance companies, public health agencies, and employers. While health outcomes were not included in this dissertation study, work that followed consensus guidelines was associated with a favorable alteration of the building environment, thus reducing the potential and risk of poor health outcomes, which may reduce disease burden and healthcare-related costs.

Recommendations

The results of this study imply that following work practices in consensus guideline documents will more often result in a successful project, which provides a reduction in potential health risks for building occupants by remedying damp and moldy indoor conditions. More studies are needed to replicate the findings under different conditions, narrow the most pertinent aspects of the consensus guidelines, and improve the applicability of the relationship between following consensus guidelines and successful assessments so that it can be applied generally to water damage and mold remediation projects. In addition, studies should be undertaken widely in southern California and replicated in various geographic locations and climates.

The use of an IEP to assess water damage mitigation and mold remediation work should be more widely employed, and additional studies should replicate the association between IEP assessments and how work is performed. Further studies should also seek to develop a standardized scope of work for IEP assessments. The use of testing for airborne mold spores as part of the IEP assessment was also associated with more passing assessments and how the work was completed. Additional studies are needed to explore this finding since the development of standardized testing, including a methodology, number, and location of samples, is necessary to validate the strength of association between the IEP assessment and also the work practices employed.

Exploratory analyses between total spore count in the work area and the pass-fail assessment by the IEP involved examining relationships between specific engineering controls recommended in consensus documents, project characteristics, and environmental conditions to determine whether there were associations and measure the magnitude of the variable relationships. Many results from the analyses with predictor variables were expected.

Additional Relevant Implications and Recommendations

Given the scope of the additional data that were collected and exploratory analyses, there were some specification associations with relevance to mold remediation projects that warrant future study to gain greater understanding of the effect magnitude and association with project outcomes. The contractor type variable was classified at three levels: (a) remediator, (b) general contractor, and (c) handyman or maintenance worker, and the analyses showed the strongest associations were between passing and remediator and failing and handyman or maintenance worker, although failing and general contractor were also associated. There was also a correlation between total spore count in the work area and contractor type, with the mean rank of spore lowest when the contractor was a remediator and highest when the contractor was a handyman or maintenance worker. Remediators were more likely to follow or partially follow consensus documents. Altogether, these findings validate the use of consensus document guidelines and may serve as the impetus for state legislatures to prompt legislation that recommends the use of consensus documents for water damage mitigation and mold remediation projects in California and other states.

There is a positive association between pass-fail and levels of containment with the strongest association between passing and containment in good condition, while there was also a positive association between pass-fail and the presence of a decontamination chamber attached to the containment, with the strongest association between failing and no decontamination chamber. Furthermore, there was an association between spore count in the work area and containment in good condition. Further research, in the form of case studies, is needed to explore the specific nature of these relationships and gain greater understanding of the relationship between these variables that may explain the necessity for specific engineering controls.

Additional research is needed on the association of importance. As one of the engineering controls, the levels of equipment (e.g., 1 = air filtration device, 2 = air filtration device + dehumidifier, 3 = no equipment, 4 = dehumidifier) should be explored further, given that it was not possible to use the equipment variable in several analyses due to missing data. Consensus documents recommend the use of air-filtration devices, fans, and dehumidifiers, but not all the IEPs recorded the equipment at the time of the PRV assessment. Moreover, a statistically significant correlation between the levels of equipment and the spore count in the work area was found, with the mean rank for spore significantly higher when no equipment or only a dehumidifier was noted. The finding implies that the use of an air-filtration device reduces the total spore count in the work area to a greater extent than other levels of equipment. Taken together, both dehumidifiers and air-filtration devices should contribute to reducing damp and moldy conditions, but the utility of the air filtration device over other types of equipment is one aspect of engineering controls in the consensus documents that should be studied on a broader scale to understand the role various appliances play in water damage mitigation and mold remediation work.

Project characteristics and associations. The age of construction was the only project characteristic that appeared to have a significant relationship with total spore count in the work area. The age of a structure relates to type of building materials, ventilation, and construction specifications that were common at the time of construction. One example is the use of whole-house mechanical ventilation which may not have been common in the early 20th century when homes did not have air conditioning and used radiant units for heating. Wall components have evolved from lath and plaster to cement board and dry wall, and interior trim has evolved from hard wood to particle board. Mentions, like these represent just a few examples of differences that occur with building age. In this study, a significant negative correlation with small effect size was observed between spore and age, and as spore count in the work area increased, the age of the building tended to decrease, showing that older homes typically had more spores in the work area than newer homes. The value of this correlation should be explored separately to determine whether older homes compared to newer homes are more susceptible to greater spore count, which may be related to the number of events that could occur over time or the type of ventilation present in the home.

Environmental condition correlations. Many environmental conditions were noted at the time of IEP assessment and included in the reports. In this dissertation study, the association between some environmental conditions, total spore count in the work area, and the pass-fail assessment of the IEP were explored.

The dissertation research revealed a statistically significant relationship between total spore count in the work area and remaining affected materials, with a mean rank for spore that was significantly lower when no affected materials were present. The correlation between pass-fail and the presence of affected materials indicates that the IEP was 86.5 times more likely to grade a pass on the pass-fail assessment when no affected materials were present, suggesting that the presence of affected materials showed that the work was not completed and potential moldy materials remained in place. Since it is generally known and accepted that indoor moldy conditions contribute to poor health outcomes for building occupants, the presence of affected materials carried the potential for health risks.

There was also a statistically significant relationship between total spore count in the work area and remaining damp materials, with a mean rank for spore that was significantly lower when no damp materials were present. The correlation between pass-fail and the presence of damp materials indicates that the IEP was 30 times more likely to grade a pass on the pass-fail assessment when no affected materials were present, suggesting that the presence of damp materials showed that the work was not completed and potential damp conditions persisted. Since it is generally known and accepted that damp conditions contribute to poor health outcomes for building occupants, the presence of damp materials carried the potential for health risks.

A statistically significant relationship between total spore count in the work area and mold type Stachybotrys was found, with a mean rank for spore that was significantly lower when no mold type Stachybotrys were present in the spore trap tests. The correlation between pass-fail and the presence of mold type Stachybotrys indicates that the IEP was 20 times more likely to grade a pass on the pass-fail assessment when no mold Stachybotrys was present. Future studies should seek to understand whether the presence of mold Stachybotrys on spore traps presents an increased risk of indoor damp and moldy conditions.

Many IEPs collect spore count in an adjacent, non-affected area, and outside for comparison with spore count in the work area. A significant positive correlation with a large effect size was found between spore in the work area and spore in the non-affected area was observed, showing that as spore in the work area increased, the non-affected area spore count tended to increase. Therefore, research is needed to examine and explore the relationships among indoor spore counts and additional engineering controls, such as containment and equipment.

A significant positive correlation with a small effect size was found between spore in the work area and outside spore count, showing that as spore in the work area increased, outside spore count tended to increase. Consequently, future research is needed to examine project characteristics such as the presence of ventilation present to understand the utility of this finding and develop standardized testing for determining the number and location for airborne mold testing as part of an IEP assessment when work is completed.

Background debris was recorded by many analysts in microbiology laboratories when processing spore trap samples, all of which were assessed quantitatively and assigned a grade by the analyst. When there is a significant amount of background debris on the slide, the likelihood that spore may be under-represented increased (EMSL, 2011). The dissertation research found a correlation between the mean rank of spore in the work area and background debris in the work area, with the lowest mean rank of spore attributed to the cleanest level of debris, whereas the highest mean rank of spore was noted at the third level of background debris, which decreased as the background level of debris increased. Given these findings, additional research is needed to understand if the calculation of debris on spore traps is relevant to the IEP assessment and air testing.

A significant positive correlation with large effect size was found between spore in the work area and hyphae in the work area, showing as spore increased, hyphae tended to increase. Since hyphae are fragments of mold growth representative of the vegetative and reproductive structures that together form the mycelium of a fungus, it can be argued that if active mold growth are present, as indicated by airborne hyphae, then more mold spores will be in detected in sampling (Burge & Otten, 1999). Therefore, future research should establish the merit of this finding and the magnitude of association.

Conclusions

The overall analysis of the relationships between work practices recommended in consensus documents, total spore count in the work area, and the pass-fail assessment by the IEP reveal several significant and meaningful associations and correlations. There was a correlation between the IEP assessment and the number of airborne mold spores in the work area, and there were significant positive correlations between how the work is performed using consensus documents and the project outcome as evaluated by the IEP assessment and testing. The benefits of recommending consensus guideline documents for water damage mitigation and mold remediation work are both physical in potentially reducing poor health effects for building occupants and financial for individuals, insurance companies, public health departments, and employers.

Like other states, California could adopt and implement legislative work practices that not only protect the health of workers but also reduce health risks for occupants of damp and moldy indoor spaces, which can be accomplished by recommending the use of work practices described in consensus guideline documents for water damage mitigation and mold remediation. The work practices outlined in the consensus guidelines may contribute to the reduction of exposure for building occupants through successful mitigation of damp and moldy conditions, thus reducing the risk of health problems related to occupying damp and moldy environments. Given the findings of this study, reducing mold exposure during remediation projects can have a direct reduction in health risks for home occupants and positive impact on public health by reducing costs associated with disease burden and reducing related morbidity.

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Appendices

Appendix A: Sample IEP Report-Lab Report

The IEP report includes highlighted areas indicating the data collected for the study dataset. Included within the IEP report are samples of a laboratory report and chain of custody. The chain of custody is shown in Appendix B. The information was gathered manually and entered into the project data questionnaire presented in Appendix C.

AQTS
AIR QUALITY TESTING SERVICES INC.

February 11, 2019

Mario Munoz
Munom5@nationwide.com
(614) 854-2777
NATIONWIDE INSURANCE

Re: Post Remediation Verification Assessment and Clearance Testing

Property Address: 820 Villa Grande St., Calexico, CA 92231
Homeowner/Insured: Haydee Holder
Claim No. 514566-GI

Dear Mr. Munoz:

As contracted, AQTS, Inc. (AQTS) conducted Post Remediation Validation Assessment and Clearance Testing on Thursday, February 7, 2019, in the residence located at: 820 Villa Grande St., Calexico, California following mold remediation in a bedroom.

Visual & Moisture Assessment:
AQTS conducted a visual assessment in the containments. Moisture readings were taken in the containment on the remaining building materials. At the time of sampling, no visible mold was observed, and no odor was present. All affected materials had been removed. Remaining building materials are dry; no elevated moisture content was noted in remaining drywall, flooring, or wood framing. The containment was in good condition at the time of sampling. An air filtration device was present in the containment. The appliance was turned to the "off" position during sampling. Inside the containment appeared clean.

Air Samples:
Air samples were collected inside the containment. A background sample was collected on the in the bedroom, outside of the containment. A sample was also collected outside for comparison. The outdoor sample was collected in the front yard area of the residence. Air-O-Cell spore traps were utilized to collect mold spores for quantitative analysis. The samples were obtained at a flow rate of 15 liters per minute (l/min) for a period of 5 minutes, yielding a sample volume of 75 liters. The samples were sent for analysis, under proper chain of custody, to SEEML, Inc. an AIHA Environmental Microbiology accredited laboratory located in Greenville, South Carolina, EMLAP #173667.

607 Idyllwild Drive, San Jacinto, California 92583 • 619.239.0774 • www.aqtsinc.com

Criteria for Passing Clearance Testing:

- Samples collected in the containment must be similar to outdoor and the non-affected area samples. ACCEPTABLE.
- The total mold spore concentration inside the contained area must be below 1,000 spores/m^3. ACCEPTABLE.
- Any individual marker molds (Stachybotrys, Chaetomium, etc.) concentrations identified must be below 100 spores/m^3 per individual spore. ACCEPTABLE.
- Work area free from debris, visible dust, visible suspect growth. ACCEPTABLE.
- All remaining building materials dry, clean, and free from water staining. ACCEPTABLE.

Conclusion:

Assessment of the containment indicates remediation work is complete. **Based on this information, the remediated area is ready for reconstruction.**

The inspection results, sample results, and conclusions are based on the conditions present at the time of the inspection. If conditions change and/or other indicators are identified, feel free to contact me.

Report Prepared by:

AQTS, Inc.

Christine A Robinson, M.S.
Principal, Industrial Hygienist
AIHA, IAQA, NEHA, ASHRAE

xc: File 19-HOL-V820

Enclosures:
SEEML, Inc. results dated 02/08/2019
Chain of Custody

Appendix B: Chain of Custody

Southeast Environmental Microbiology Laboratories

Chain of Custody

506-A Laurens Rd, Greenville, SC 29607

Phone : 864-233-3770, Fax: 864-233-3779, www.seeml.com, AIHA-LAP, LLC (EMLAP) #173667 Page 1 of 1

For Lab Use Only			
Condition of samples is acceptable	☑ YES ☐ NO	SEEML Ref #: 19020802-1	Lab ID: 062-064

Company Information	Client Information		Environmental Conditions	
C. Robinson	Date Sampled:	19-COL-V820	Precipitation in last 16hrs:	
AQTS, Inc.	Project Name:	2/7/2019	Relative Humidity I/O:	45 / 25.6
607 Idyllwild Drive	Project Address:	820 Villa Grande St	Temperature I/O:	66 / 63.1
San Jacinto, CA 92583	City, State, Zip:	Calexico, CA 92231	Wind Conditions	
(619) 239-0774				
testing@aqtsinc.com				

Sample Type Abbreviations:
A- Allergenco S-Swab AP-Andersen Plate
AOC- Air O Cell T-Tape W- Water
MS- Micro 5 B- Bulk D- Dust

Analysis Type:
1. SporeTrap, Air Sample Analysis-Same Day
2. Direct Exam Surface Sample Analysis -Same Day
3. Culturable Air / Surface Samples -7-10 days

Sample ID	Sample Location	Sample Type	Analysis Type	*Area	**Volume (L)	Notes
2609 2144	Outside - Front	AOC	1		75	8/135 63/26
2609 6741	Bedroom	AOC	1		75	8/1100 664/45.1
2609 0767	Containment	AOC	1		75	8/1079 69.3/46.9

Relinquished By:	Date/Time	Recieved By:	Date/Time
[signature]	2/7/19	[signature]	2-8-19

* Area is only required for culturable surface samples.
** Volume = Pump setting (L/min) x minutes

Form 21.0 Rev. 2 12/19/14

Appendix C: Project Data Questionnaire

The project data questionnaire was used with each project. The IEP provided the data from each project gathered from the chain of custody, laboratory report, final report, job photographs, and job notes. An email containing the following verbiage was sent to each IEP after initial contact was made via telephone.

Date:

Dear company:

I am in the process of working towards a PhD in health sciences at Trident University. The focus of my proposed dissertation is to understand if there is a relationship between work practices recommended in consensus documents and the resulting airborne mold spores and pass-fail epic project. Specifically, I am looking at work practices contained in the IICRS S500 and S520 and the resulting report by the IEP.

I am seeking participation from an IEP to provide data for this research. All project data, client names, contractors, laboratories, and project addresses will remain confidential.

Enclosed you will find a survey form. This is the information that we would like to use in the project. We would be happy to provide man hours and resources to gather this data from your records. Please contact me at cellphone if you would like to participate in the study.

Signature line.

SURVEY

Please complete one form for each containment or affected area. There may be more than one form for a project if there is more than one affected area. Please only include residential projects that concluded with Post Remediation Verification and Clearance Testing and has a full IEP report indicating if the project passed or failed. These words need not be used so long as the report contains a conclusion, i.e., “no further assessment is warranted” or “the project is ready for reconstruction,” etc. Data should be collected and recorded from the IEP report, laboratory report, chain of custody, and job notes or photos. Incomplete projects are ok so long as there is a report and laboratory result. Retests should be included using a separate survey form for the original test and the retest. All information gathered will remain confidential and be used solely for this research dissertation. If additional use is desired, a separate request will be made.

Name of IEP completing this questionnaire: ____

Project Number: _________________________________ Date of Report: _____________

Affected/work area: ____

Source of loss if known:____

Raw spore count in work area/containment: ___________ Did project ☐ Pass or ☐ Fail?

Laboratory name: ____

Temperature (F) in work area: ____________ Relative Humidity in work area: ____________

Raw count hyphae: ___________ Background debris: _______

Raw count spores outside sample: ______ Raw count spores indoor background sample: ______

Was Stachybotrys found on the sample in the work area/containment: ☐ Yes ☐ No

Did contractor follow recommendations in consensus documents (S500 or S520)?

☐ Did Not follow

☐ Partially Followed

☐ Did Follow

Contractor name: __________________________________

Contractor Type: ☐ Remediator; ☐ General Contractor, ☐ Handyman/Maintenance Worker

Containment: ☐ Yes, Good Condition; ☐Yes, Fair Condition; ☐ Yes, Poor Condition; ☐ No

Decontamination chamber present: ☐ Yes ☐ No

Appliances in the work area: ☐ Fan; ☐ Dehumidifier; ☐ AFD (air scrubber); ☐ None

Remaining Damp materials in the work area: ☐ Yes ☐ No

Remaining Affected materials in the work area: ☐ Yes ☐ No

Was more than one area affected: ☐ Yes ☐ No Is this a retest of a failed test? ☐ Yes ☐ No

Notes (please make any notes you feel may be useful for this project):____________________

____

____

____

☐ I certify to the best of my ability that the information provided in this survey is true and accurate.

___________________________ _______________

Signature Date

Appendix D: IRB Approval

TRIDENT UNIVERSITY
INTERNATIONAL

Office of Institutional Research
Institutional Review Board
5757 Plaza Drive, Suite 100, Cypress, CA 90630
Office: (714) 816-0366 ext. 2518 | Fax: (714) 226-9844

Memo
From Simcha Pollard, Ph.D.
Chair, Institutional Review Board of Trident College
Re: IRB approval IRB # 1064

Protocol and Study Information	
Date Submitted to IRB: Submitted 4/23/2019 Approved 4/30/2019	
Principal Investigator: Christine Robinson	Research Advisor: Dr. Bill Tawil
Proposal Title: MOLD REMEDIATION PRACTICES ASSOCIATION WITH REMEDIATION RESULTS FOR RESIDENTIAL STRUCTURES IN SOUTHERN CALIFORNIA	

Investigator Information			
	Name	Department	
Christine Robinson CHHS			
Co-Investigator			
Co-Investigator			

I am pleased to inform you that Trident University IRB has approved your project: Exempt. Exemption is based upon Research involves collection or study of existing data, which does not contain identifiers linked to human subjects (CFR 46.0101(b)(4)), which is being evaluated. You will need to upload your approval letter into the IRB Approval Folder in your 800 Drop Box. Reapplication is not required in a year if the study is still being conducted. The committee has reviewed your study. Please feel free to start your study at any time.

Best wishes and good luck,

Simcha (Stephen) Pollard Ph.D.

Simcha (Stephen) Pollard Ph.D.

v. 05/28/14

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Appendix E: Access to AQTS Project Data Permission Letter

AQTS | AIR QUALITY TESTING SERVICES INC.

February 21, 2018

Trident University
Institutional Review Board for the Protections of Human Subjects
5757 Plaza Drive, Suite 100
Cypress, CA 90630

Re: Access to AQTS Project Data
Christine Robinson – Dissertation Research Study

Dear IRB:

On behalf of AQTS, Inc., I am writing to grant permission to Christine Robinson, a doctoral student at Trident University, to conduct her research study titled "The Outcome of Water Damage Mitigation and Mold Remediation Projects that Follow Consensus Document Recommended Work Procedures."

I understand that Christine Robinson will review project records for assessment and remediation projects completed since 2008. I understand that she will fill out a data sheet for each qualified project. I have looked at the data sheet, and no health information or information about the building resident is being collected. I understand that data collected will be done in our office by Ms. Robinson over the next several months.

I expect that Christine Robinson will keep confidential all of the data collected. She has explained that a unique identifying number will be used in place of the project number, contractor name, and name of the individual performing the assessment and testing. It is expected that this information will remain confidential so as to protect the reputation of the companies, clients, employees, and project address.

We are happy to participate in this study in the hope of providing much needed validation for the work practices involved.

Sincerely:

AQTS, Inc.

Christine A Robinson
Owner and Sole Corporation Officer

3639 Midway Drive, #B-407, San Diego, California 92110 • 619.239.0774 • www.aqtsinc.com