MOLD SUSCEPTIBILITY OF

RAPIDLY RENEWABLE MATERIALS USED IN WALL

CONSTRUCTION

A Thesis

by

AARON MCGILL COOPER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

December 2007

Major Subject: Construction Management

MOLD SUSCEPTIBILITY OF

RAPIDLY RENEWABLE MATERIALS USED IN WALL

CONSTRUCTION

A Thesis

by

AARON MCGILL COOPER

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Chair of Committee,	Charles W. Graham
Committee Members,	David G. Woodcock
	Sarel Lavy
Head of Department,	Joe Horlen

December 2007

Major Subject: Construction Management

ABSTRACT

Mold Susceptibility of

Rapidly Renewable Building Materials Used in Wall Construction.

(December 2007)

Aaron McGill Cooper, B.S., Brigham Young University

Chair of Advisory Committee: Dr. Charles W. Graham

Since 1998, the United States Green Building Council, via the Leadership in Energy and Environmental Design (LEED) standards, has established the premiere set of guidelines for construction ethics from the standpoint of eco-friendliness and occupant safety and health in the U.S. and around the world. These guidelines are skyrocketing in use due in part to two reasons:

- increased awareness of a need for reducing, reusing, and recycling in order to save resources and natural areas for future generations; and,
- increased amount of time spent indoors in work places and homes.

The LEED guidelines encourage sustainable and responsible use of land, water, energy, and materials, and promote a safe and healthy environment through use of innovative designs and technology. As part of the responsible use of materials, the LEED guidelines encourage the use of rapidly renewable materials such as cotton, straw, wool, and cork as insulation products. Although these products can be produced naturally and quickly from nature, they are also cellulose or carbohydrate based products. Cellulose and carbohydrate based materials are typically optimal food sources for mold in the presence of moisture, ironically destroying facilities and creating poor living and work environments.

Samples of wool, cork, straw, and cotton--rapidly renewable materials used as exterior wall insulation products--were exposed to different moisture amounts in an encapsulated environment, representing the environment within a wall cavity when exposed to water from pipes, leaks, condensation and absorption, or from initial construction. The samples were monitored over time for mold growth.

The data logged from the samples were analyzed to determine the degree of mold susceptibility of each material. In addition, samples with increased amounts of moisture were examined to determine increased promotion of mold growth. The results from this study showed that all of the above mentioned materials were highly susceptible to mold growth and that the moisture amount did not increase the rate of mold growth. Based on the data collected from this study, recommendations were made to review the current use of rapidly renewable and other cellulose and carbohydrate based materials in wall construction.

ACKNOWLEDGEMENTS

I would like to thank the United States Air Force for the amazing opportunity to dedicate 18 months to the task of learning about mold and how it relates to construction. I would also like to thank the faculty, staff, and my Aggie family at Texas A&M for their support and continuous effort to create an incredible learning atmosphere and a second home. I am also truly grateful for a recognized mold expert, Dr. Charles Graham, and for all of the time he shared with me discussing mold and passing on what he has learned from many years of first-hand experience and the time and knowledge of my committee members Professor David Woodcock and Dr. Sarel Lavy. I also had tremendous help from Dr. Rudolpho Aramayo, an experienced and enthusiastic mycologist, with examining, culturing, and photographing the mold in the post experiment work; and from John Peters, the Texas A&M College of Architecture Audio Visual Specialist who took fantastic photographs. The non-stop encouragement and positive feedback from my wonderful parents Jerome and Anne Cooper, and my amazing grandmother Stella Zaleski, have also always been an inspiration to me. Last and most of all I would like to thank my beautiful and extremely talented wife Cristyn for attempting to appear interested in our many long discussions on fungus, for energetically taking on the task of editing, and for all of the extra time she put in maintaining our family of young mycologists who now try to relate all things to mold---Grant, Breanne, Lauryn, and Aggie baby Jackson.

TABLE OF CONTENTS

LIST OF FIGURES

Page

Page

LIST OF TABLES

Page

INTRODUCTION

Background

The world's human population continues to increase, and so does the amount of natural resources used to sustain this population. As of 1999, the world manufactured more than eight times the volume of goods it did just 50 years earlier. This statistic becomes even more staggering in light of the fact that the majority of the world's population is just beginning to develop and thus beginning the consumer cycle. Because the world's natural resources are limited, a push for sustainable construction of new buildings and homes has come about (Harland, 1999).

The United States Green Building Council is considered the premiere source for sustainable construction guidelines in America, through their Leadership in Energy and Environmental Design (LEED) program. This program, found in the brochure *Green Building Rating System for New Construction and Major Renovations*, encourages contractors to utilize construction methods and techniques that will conserve natural resources, create a healthier environment, and avoid waste. According to links on the U.S. Green Building Council web site, LEED is quickly becoming the mandatory building standard for U.S. military and government buildings. In addition, many states, universities, and municipalities are using LEED as a benchmark for building standards and local codes. LEED standards are growing in popularity around the world, as other countries are using LEED guidelines as a model to create similar programs (U.S. Green Building Council, 2006).

One of the LEED recommendations is to use rapidly renewable materials for at least five percent of construction materials. Rapidly renewable materials are easily renewed by nature, so their use has a low impact on the environment. New products using rapidly renewable materials are being created daily to satisfy the skyrocketing demand for LEED certified building products. According to the Association of General Contractors of America, there are over 1,200 new products waiting for LEED certification (Association of General Contractors of America, 2006).

This thesis follows the style of the *International Journal of Construction Education and Research.*

Most rapidly renewable materials are organic materials rich in cellulose and carbohydrates. Ironically, cellulose or carbohydrate based materials are also very good nutrient sources for fungi. Fungi, unlike plants, do not contain chlorophyll and therefore must use organic food sources for nourishment. A common fungus which has gained much notoriety in recent years due to high profile and expensive insurance claims is mold. Mold is not a new phenomenon. Mold has been around for thousands of years and can be found literally everywhere. Since mold spores can be found everywhere, any environment that supplies the necessary temperature range, moisture content, and a food source can become a hospitable environment for mold to grow and germinate—including indoor areas (Owen, 2006).

Since the energy crisis in the 1970s, the drive to make homes more energy efficient has led to an industry-wide practice of making building envelopes progressively tighter, decreasing ventilation and significantly reducing outdoor air exchanges. Increased use of vapor barriers and insulation traps and encapsulates moisture within homes, wall cavities, ceilings, and attic areas. Although tighter building construction practices save energy, they also can create an environment of stagnant air that is highly hospitable to mold. Undesirable moisture is then introduced by unavoidable activities such as showering, cooking, cleaning, and sweating, along with unplanned events such as spills, overflowing toilets, or plumbing malfunctions. In addition, water from outside the home can be introduced through moisture absorption from the exterior, facility cracks and penetrations, and leaky windows or roofs. (Lieff & Trechsel, 1982). Because a damp environment *will* eventually be created, construction methods and architectural designs that fail to incorporate the ability of walls or individual materials to handle liquid and vapor moisture movement will lead to problems, including mold (Schwartz, 1992).

Mold becomes problematic when it is found in high concentration indoors where it can be detrimental to the health of humans and pets. According to Douglas Owen in *Mold: Inspection, Problems and Solutions*, “Americans spend an average of 75%-90% of their time indoors...” (Owen, 2006). Molds produce allergens, irritants, and toxins which can cause health problems. Health effects range from common cold symptoms, rashes, and allergies to severe asthma, extreme sensitivities, and weakened immune systems. If mold is found within wall cavities, extremely difficult and potentially costly mitigation will need to take place, including the removal and replacement of interior wall coverings and insulation (Douglas & Sterling, 1997; Pugliese, 2006).

Rapidly renewable products, due to their high cellulose and carbohydrate content, are highly susceptible to mold when exposed to moisture. Therefore, these materials may not be a part of a good long-term solution to sustainability as wall building materials.

Statement of the Problem

In addition to being capable of regular harvesting, numerous rapidly renewable materials have desirable strengths and qualities. These high cellulose based materials will be sealed within or against wall cavities, initially being dry or at equilibrium with the existing moisture in the air. However, these materials may eventually wick or hold unintended moisture. Because of high cellulose content, rapidly renewable resources made from wood, straw, cork, cotton, and wool may be more susceptible to mold compared to other non-cellulose traditional wall materials made from clay, cement, steel, fiberglass and gypsum. If so, rapidly renewable materials may not be desirable as long-term sustainable construction materials. Because little is known about the effects of rapidly renewable materials exposed to moisture over time, studies are needed to better understand how these materials will react in the presence of moisture.

Outline of Study

This study took place in the following stages:

- Study of the background and ecology of mold,
- Collection mold growth data from rapidly renewable material samples,
- Analysis of the data for significance,
- Transplantation of mold spore samples for growth in controlled Petri dishes, and
- Identification of the types of mold within study.

Research Hypotheses

The following research hypotheses were used to provide structure for this study:

- Rapidly renewable materials will grow mold when exposed to moisture,
- The rate of mold growth will increase in the presence of additional moisture, and

- Mold will grow at different rates based on the individual material.

Statistical Hypotheses

The following statistical hypotheses were used to provide structure this study:

- Ho: all of the materials = zero mold growth over time,
- Ho: moisture levels = zero difference in mold growth, and
- Ho: all materials will act alike, wool = cork = straw = cotton.

Limitations

This research studied four different materials and monitored 36 samples. This scope was limited due to time and budget. In addition, although the experiments tried to emulate field conditions, the tests were all performed in a controlled manner which can never be a perfect simulation or reflection of field conditions.

Delimitations

The following delimitations were set for this study:

- This study is only of mold susceptibility; additional material qualities were not evaluated,
- This study evaluated cork, straw, cotton, and wool, and not additional rapidly renewable materials, including composites which contain the selected evaluated materials,
- This study evaluated the effects of moisture using 0, 25, and 75 mL of water, used to represent a control group, low moisture, and high moisture respectively.

Definitions of Terms

The following definitions were incorporated in this study:

- **Biocide:** substance or chemical used to kill organisms, including mold,
- **Cellulose and carbohydrate base materials:** materials retrieved from plants or animals,
- **Conidiophore:** conidium or flowering body and phore is the bearer or shaft, the mushroom or fruiting body of the mold that gives off spores,

- **Dew point:** the temperature at which moisture will condense from the air, turning water in an air state to a liquid state,
- **Encapsulation:** area where air is stagnant and not changing,
- **Filamentous fungus:** masses of hyphae, or strand networks that are used to sustain mycelium,
- **Fruiting bodies:** flowering growth in molds that creates and sends out spores,
- **Fungicide:** a chemical used to kill fungi or mold growth,
- **Germling:** first product from the germination of a mold spore creating the potential for a hyphae,
- **Germ tube:** growth extensions from an individual hyphae allowing the mycelia to expand and move within an area typically to an area more condusive to mold growth,
- **Green building:** construction that uses LEED guidelines, or the movement to use natural products in construction,
- **Hypha, plural hyphae:** main elongated individual units that make up a community of mold—the units responsible for the digestion for the community,
- **LEED construction:** construction that uses sustainable, environmentally friendly, and health conscious techniques based on Leadership in Energy and Environmental Design guidelines—this study refers to LEED version 2.1,
- **Mold**: a generic term to define fungal growth,
- **Mold susceptibility:** tendency of an item or material to mold,
- **Mycelia, plural mycelium**: first visible groups or communities of mold consisting of millions of hyphae,
- **Rapidly renewable materials:** materials harvested from plants or animals in a cycle that is more frequent than the average useful life cycle of the material, and
- **Relative humidity:** (RH) a measurement of how much water vapor is in the air at any given temperature and a comparison of the amount of water vapor that can be held in the air at a temperature—as air temperature rises, so does the air's capability to hold water.

Assumptions

The following assumptions were incorporated in this study:

- The simulated encapsulated environment emulates realistic wall environments,
- The rapidly renewable materials tested were isolated from additional factors that could cause variations in the test results, and
- Results from analyzing mold susceptibility of rapidly renewable materials can have relevance to construction for LEED facilities.

Significance

In order to avoid mold, it is important to understand the relationship between construction materials and their susceptibility to mold in the presence of moisture. LEED construction guidelines are becoming a standard for construction within the United States and around the world. LEED guidelines place an emphasis on the use of specific materials, including rapidly renewable materials, for construction. Because rapidly renewable materials have a high cellulose or carbohydrate content, a favorable food source for mold, it is important to ensure that these materials are not prone to mold growth.

Mold growth within indoor environments can pose serious health effects due to inhalation and ingestion of conidia, spores, and mycotoxins. Figure 1 depicts people, including children, removing mold-infected drywall from a home in an area flooded by Hurricane Katrina. According to an article in USA Today, many New Orleans residents have “Katrina cough”, a respiratory problem (Szabo Liz, 2006).

Figure 1. Mold remediation work following Hurricane Katrina (Szabo, 2006).

REVIEW OF LITERATURE:SUSTAINABILITY

Introduction

The world population is on the rise (Kibert, 2005), with the current population close to 6.5 billion and growing quickly. Many developing nations around the world are also modernizing at a rapid pace. The sharp increase in population and modernization has led to a seemingly endless demand for resources. This demand for goods will continue to skyrocket. Clean potable water is necessary for hygiene, sanitation, nourishment, and the production of goods. Energy and power sources are critical for transportation, technology and comforts, and communication and education. Abundant natural resources are required to build and maintain infrastructure, facilities, and homes (Moser, et al., 2003). Alarming signs are taking place that demonstrate the almost unfathomable reality that the earth does have a finite amount of resources and that many of these resources are becoming scarce. The earth's forests are shrinking, deserts are expanding, top soil is eroding, species are declining, and the ozone layer is disappearing (Brown, 1988). As resources are removed, altered, or destroyed, ecosystems are changing too, the effects of which can be hard to measure. Much debate has taken place over how to manage these growing needs in a world with finite resources. If all of the resources are destroyed, what will future generations have to sustain their needs? A sustainable society has to be able to satisfy its needs without diminishing all chances for support to future generations. An honest examination of current habits and trends must take place to determine the long-term ecological effects current practices will have on our earth.

Disposable Society

Waste, the amount of unused product discarded on a daily basis, is one the most alarming trends that our world faces. According to *Nature's Interest*, (Chambers, et al., 2000), the amount of natural resources used each day continues to increase. In 2000 our average use was four kilograms of resources for each person in the world every day. This number did not even take into account the amount of resources that were consumed in order to create a product, such as mining waste or trees that were cut in order to attain the desired resource. With the globalization of economies and companies, shipping has become a huge additional source of consumption and waste, creating a need for extra packaging as well as using resources during transportation. In addition, not only do many consumer goods come with a disposable wrapper, but the product itself is also meant to be thrown away after a single use. According to the book *Concrete Jungle,* as of 1996 the single largest garbage collection dump in the world was a nearly 3,000 acre landfill on New York's Staten Island called Fresh Kills. Fresh Kills collected all of the garbage for New York City from 1948 to 2001, competing with the Great Wall of China for the title of largest man-made structure in the world and securing the dubious honor of being the largest collection of garbage in the world (Dion & Rockman, 1996; Wikipedia, 2007a).

It seems logical that the most effective way to slow our global rate of resource consumption is to reduce our use, reuse products, and recycle them at the end of their useful lives. However, creating incentives for people, companies, and nations to practice the "three R's" (reduce, reuse, and recycle), and developing recycling methods that are truly effective continues to be a challenge. Some organizations are addressing the issue of waste by shifting their use to products or materials which are rapidly renewable, or which can be replaced quickly. This practice appears in the short run to solve some of the problem of depletion of natural resources since the resources used are renewed in tens of years instead of hundreds, but it fails to deal with the issues of resources consumed in production, transportation, maintenance, and disposal, and does not address the issue of waste.

Life Cycle Analysis

The true impact of a material can be derived from a life cycle analysis. A life cycle analysis reviews the entire life span of a product and accounts for the energy and resources required to create it, maintain it through a useful life, and then dispose of or recycle the item after its useful life. A life cycle analysis may seem simple, but indirect energy and resource impacts can sometimes be hard to measure or even understand. Any effects that can be measured, should be, in order to generate a realistic measurement of the impact of a product (Chambers et al., 2000).

Sustainable Push, a Natural Trend

With the eye-opening results of life cycle analysis in mind, sustainability is becoming an important concern, encompassing many topics from waste and energy consumption to the types of products used in the production of homes and buildings. In addition there is a growing desire to return to nature. This places an emphasis on the natural ecosystem that sustains the human existence and serves as a constant reminder that the earth must be viewed as a living set of ecosystems that all work in harmony with each other. The 1992 Earth Summit in Rio de Janeiro, Brazil brought together numerous programs and ideas in conservation and sustainability. One of these is the idea of a global revolution that starts at a grass roots level in every country in the world, working together for environmentally friendly changes. Previous summits had pushed for a unified arm from the United Nations or a new and separate group that would have power to enforce international environmental restrictions and laws. However, the new grass roots method was adopted due to the realization that nations will rarely work in harmony or follow international laws in the absence of some sort of economic, social, or strategic benefit.

By taking the movement to the individual, there was a hope to create a shift away from competition and continual expansion and toward an attitude of cooperation and conservation, based on the idea of self-limitation and preservation (Bosselmann, 1995). Placing responsibility for sustainability on the individual eventually pushes the same desire up to small businesses and corporations. According to *The Business of Sustainability*, most managers when discussing sustainable practices and ethics with managers from diverse businesses, felt that the concept of sustainable development would become an important practice in the future (Steger, 2004).

Sustainability on a Macro Level

In an opposing view to the concepts developed in the Rio summit, Huey Johnson in *Green Plans Greenprint for Sustainability*, argues that it is critical for industrialized nations to quickly come up with a comprehensive plan that can mandate macro level solutions to the problems of sustainability in order for societies to live within their means and to reduce the expanding negative ecological foot print of the population. Small scale efforts may look good at a glance, but they have little measurable effect in the long run

(Johnson, 1995). The importance of being able to observe and measure improvement in the environment as a direct result of human actions can not be underestimated, since we must bear in mind that unless they are forced to do otherwise, people will act in their own self interest, whether to promote their own importance, grow their company, or simply make life more convenient for themselves. Since we as individuals can not always see the long term effects of our choices, it is Johnson's belief that we must be forced to behave in ways that preserve resources.

Time Scale

As technologies develop and the production of consumer products increases to supply the rapidly growing world population, small changes due to pollution and utilization of resources create small but significant changes to the environment. John Robinson in *Life in 2030: Exploring a Sustainable Future for Canada*, points out that there is a real "mismatch" in scales of measuring results and predicting outcomes to the sustainability and health of environmental systems and how people perceive and view time. The typical life span of a person is less than 100 years. Even less than this is the measurement of a person's working career; and the amount of time one person will spend in any one position with any one company is shorter yet. However, daily the seemingly small choices made by a company or individual have very significant impacts on the world of tomorrow. When companies do put forth an effort to make eco-friendly decisions, they are often disappointed when they do not see a quick and measurable impact that can be advertised to their customers and used to gain an edge over their competitors. Unfortunately nature's time scale does not move at the same pace as human business. Because of this, we must find a way to accurately measure the long-term outcomes of decisions in order to curb practices that will be hazardous to future generations (Robinson, 1996). Many construction and production trends are developing which claim to be sustainable but which still need to be subjected to further examination and complete Life Cycle Analysis to determine their real effects.

Green Building Trend

The concept of Green buildings or environmentally friendly construction is not new. However, the effectiveness of different construction practices and ideas is hard to measure, and the methods of measurement themselves are a point of debate. The U.S. Green Building Council attempted to change the vague and touchy feely concept of "Green" into something that was definable and measurable with the development of the Leadership in Energy and Environmental Design (LEED), version 2.1 standards. Table 1 shows a breakdown and weighting by points of the different categories for a total of 69 possible LEED points. See Appendix A for a complete breakdown of all of the individual LEED points.

Table 1. LEED construction guideline categories, (Kibert, 2005).

LEED New Construction Guideline Categories		
	Category	***Max. Points***
1	Sustainable Sites	14
2	Water Efficiency	5
3	Energy and Atmosphere	17
4	Materials and Resources	13
5	Indoor Environmental Quality	15
6	Innovation and Design Process	5
	Total Possible Points	**69**

The primary theory of construction that is encouraged by the U.S. Green Building Council's LEED assessment standards is that spending more effort and money on the initial investment in the design and construction phase will translate into big savings on utilities, maintenance and capital replacement costs throughout the life of the facility, with the added bonus of creating a cleaner, more pleasant workplace and a more environmentally friendly facility (Kibert, 2005). Charles Kibert discusses three main reasons for a critical need for Green construction in the United States and in the rest of the world---Responsibility, Money, and People. Building Green is the ethical response to the growing need for sustainability in the world. Sustainable construction encompasses the entire life cycle and foot print of a facility to include not only all of the life cycle costs of the building, utilities, maintenance, and capital replacement, but also the extraction of the materials, source of the required energy, and deconstruction. Green construction also makes sense financially when all life cycle costs are considered. Higher upfront costs are recovered over the life of a facility. The LEED guidelines also take building occupants into consideration. There are numerous employee illnesses related to construction materials and methods, such as Sick Building Syndrome (SBS), Building-Related Illnesses (BRI), and Multiple Chemical Sensitivity (MCS). LEED standards focus on indoor air quality, including temperature, humidity, mold, offgassing finishes, and lighting. By personalizing a facility to the end user's needs, safety, wellness, and comfort, the LEED building guidelines can result in happier, healthier, and more productive workers.

According to an article on 8 May, 2007 in the *Financial Times*, the cost of pursuing green construction is dropping dramatically, by as much as 80% in some areas compared to costs for LEED certification since 1998. Buildings pursuing a green rating from the US Green Building Council's LEED ratings system rose by 50 percent from 2006 to 2007. These buildings account for six percent of all construction in the United States, over one billion square feet. To be LEED certified, a minimum total of 26 points is required. Points ranging from 26 to 69 certify facilities at different levels, see Table 2.

Table 2. LEED construction ratings, (Kibert, 2005).

LEED Construction Ratings	
LEED Ratings	***Points Required***
Platinum	52-69
Gold	39-51
Silver	33-38
Certified	26-32
No Rating	< 25

The demand for the environmentally friendly buildings and work spaces is increasing just as fast. Many companies, clients, and employees are placing the LEED certification as a high priority for new workplace and business selections. In addition, numerous states and cities are giving substantial tax incentives to encourage even further growth (Pimlott, 2007). According to an article on *MSN City Guides*, "American cities aren't just starting to blossom in the green arena, they're fighting to see which can bloom the brightest. The U.S. Green Building Council has set the benchmark for efficient and healthy construction with the LEED (Leadership in Energy and Environmental Design) Green Building Rating System, and many cities are hustling hard to attract this kind of development" (Gordan, 2007).

With more builders and owners pushing not only for a LEED rating, but higher standards within the LEED certification, a new and growing demand for Green materials has emerged. Materials and Resources, LEED category number four worth 13 points, covers the use of different types of materials, including recycled and rapidly renewable materials. Rapidly renewable materials are defined as materials that can reach maturity in a period of ten years or less. Rapidly renewable materials come from renewable natural resources, (plants or animals) and reduce the use of limited natural resources. In addition, this LEED category uses recyclable materials, many of which utilize waste paper, an abundant and available resource (Green Maker Building Supply, 2007). The production of products that use these materials has minimal impact on the environment. Figure 2 is just one example of a new "Green" construction material, a natural insulation recently highlighted by *USA Today*, grown from a fungus to be used in homes and buildings, which has recently emerged as part of the huge growing market for sustainable materials. The Green building movement, through the creative innovation of the LEED certification process from the U. S. Green Building Council has filled a growing need and desire for people around the world to create a more sustainable world for future generations.

Figure 2. Mushroom/perlite composite insulation growing in a dish (Chua, 2007).

Sustainability Conclusion

Sustainability is going to be very important for the generations of tomorrow. People must start taking action now in order to have an impact on the future. The United States Green Building Council has taken a very positive step toward sustainability with the LEED construction guidelines. The guidelines are a good fit with today's societal desires to see quick direct and impacting results. The LEED certification process is like a pill to help new building owners, users, and builders not only feel like they make a difference, but directly see it each time they see the building's label of silver, gold, or platinum. Because of this, the LEED movement is catching on and growing extremely fast. The United States Green Building Council discovered a fantastic technique for answering a sustainable need in our society and around the world. Unfortunately, the same fast and impacting result mentality that makes the LEED guidelines such a success bring with it potentially dangerous and hazardous flaws. LEED's advocacy of the use of rapidly renewable materials and recycled materials that include natural products containing cellulose and carbohydrate based products is a dangerous path.

Although rapidly renewable and recyclable materials are abundant resources that can be produced with minimal impact on the environment, they are not always a good choice as a long-term construction component. These materials are being used to replace synthetic materials or non-renewable resources as building materials. Rapidly renewable materials, because they are natural and come from living plants and animals, are cellulose or carbohydrate based. When this type of material is combined with moisture, it becomes an optimal nutrient source for fungi. When sections of buildings are highly susceptible to mold, then they must be removed or destroyed quickly once they become exposed to moisture. If the building sections are critical, then the entire building may need to be destroyed. Could these new materials be creating a new generation of disposable facilities? This would only seem to add to our “disposable society”, thus diminishing the push to become more sustainable.

Businesses, governments, and individuals must make responsible choices even if they do not receive any personal benefits or recognition. Groups and individuals can not continue to do nothing because they can only do a little. LEED is a great program that helps individuals and groups make the correct decisions. However, some of the materials within LEED need to be more closely examined, or the only Green for the future of these new LEED certified buildings may be the layers of mold growing within the walls.

REVIEW OF LITERATURE:ECOLOGY OF MOLD

Introduction

Mold has been around for millions of years and can be found virtually everywhere. Molds are a division of the Fungi Kingdom, which includes an estimated one to two million species. Molds are heterotrophic organisms. According to the online encyclopedia wikipedia, heterotroph comes from the Greek words "heterone" meaning other, and "trophe" which means nutrition. A heterotroph is a consumer, and utilizes organic substances in order to attain needed carbon to sustain life. "A heterotroph is an organism that is incapable of making its own food from light or inorganic compounds, and feeds on organisms or the remains of other organisms to get its necessary energy to survive" (Wikipedia, 2007b; Kavaler, 1964). Since molds can not create their own food, they form a symbiotic relationship to attain necessary nutrition, which they do through absorption. Mold can utilize once living organisms (saprotrophic), attach to living organisms by feeding directly from the host (biotrophic), or consume by-products that a host no longer needs (necrotrophic). These relationships can also be described as neutralism, antagonism, or mutualism respectively. Molds also do not ingest food. Instead, molds secrete enzymes onto nutrient rich substrates. The enzymes break down the substances into simple carbon-based food sources that can be absorbed through the cell walls and utilized for nourishment (Cooke & Whipps, 1993).

Molds are multi-celled organisms that belong to the eukaryote domain. Eukaryotes are complex celled organisms that have structured cells that not only define the shape of the cell, but also the organisms themselves. Eukaryotes also have a nucleus with DNA and chromosomes. Eukaryotes grow via assexual cell division or mitosis and reproduce through cell fusion or meiosis (Wikipedia, 2007c). The overall mold structure is created mainly from individual units called hypha. Hyphae that are massed together into a community are called mycelia—see Figure 3 (Worrall, 1999). Mycelia act as a true networking community with the purpose to survive and spread to additional colonies. As some areas become unfit for living conditions due to lack of moisture, food, or an introduction of a harmful agent such as heat or a chemical, the hyphae within a mycelia will share or pass any remaining nutrients by sending plasma to the leading or colonizing edge of the mycelia.

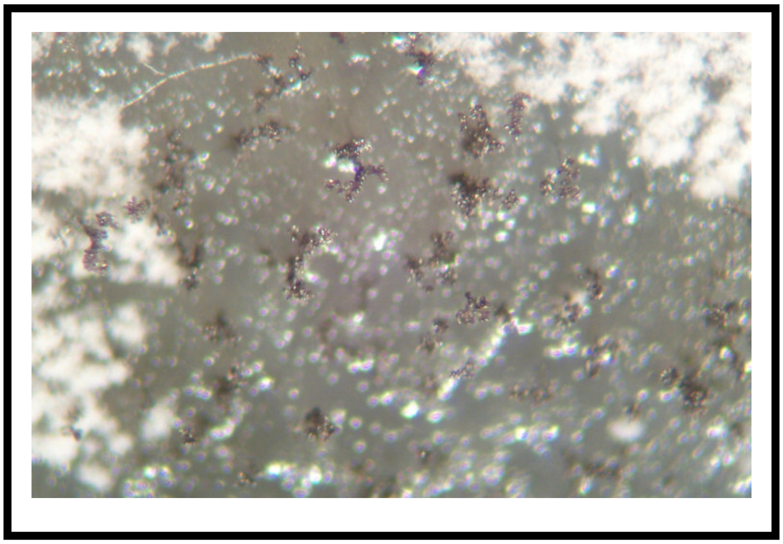

Figure 3. Mycelium--visible communities of hyphae.

Ideal Conditions and Requirements for Mold Growth

Mold is an amazing survivor. Mold can adapt to nearly every scenario, with the ability to wait for proper conditions to return or spread to new locations prior to going dormant. Mold can survive with minimal growth in non-ideal conditions concerning temperature and humidity and can survive off of airborne nutrients found in floating skin cells, dander, or carbon dioxide from the atmosphere. In this survival mode, no spores will be produced and growth will stop, but the mold is still alive (Jennings, 1993). Mold can survive and grow in almost any environment and has even been found in some cases to live without oxygen under water, or to attach to non organics, including rocks by surviving off of residues, plants, and bacteria and still grow (Cooke, 1993). Although mold has been seen growing in almost every condition, including extreme temperatures, moisture, and environments, mold does have some typical requirements for it to grow and thrive easily. Once spores are introduced to a food source, mold usually has several ideal environmental conditions:

- Temperature ranging from 70 to 90 degrees Fahrenheit,
- Moisture, water, or very high humidity,
- Relative Humidity of 50 percent or higher,
- Darkness,
- Stagnant air, and
- Environmental pH that is higher than seven (Progovitz, 2003).

As mentioned, these items are not completely necessary, and mold can certainly grow and sometimes flourish outside of the listed ideal scenario, but when the above conditions exist, the probability of mold is extremely high. As for the food source, mold, in most cases, must obtain carbon from either living or once living sources, so plant matter or debris or materials made from plant matter become an easy host food source for mold. “Cellulose is the most abundant substance in plant litter and a major constituent of all the layers of plant cell walls. It forms about 30-40% of the dry weight of wood and can be as high as 45% of the dry weight of cereal straw” (Dix, 1995). Carbohydrates found in plants or animals and can also be easily utilized by fungi or mold and can easily be converted to a high glucose food source. Items that are cellulose or carbohydrate based include almost any plants, animals, or any item that is made from a plant or animal. These items would also include left over human food sources, pet food sources, clothing, books, boxes, and paper products.

Mold Spores, Germination, and Growth

The spores’ primary function is reproduction, but they are also essential for mobilization, growth, and survival. Mold spores are extremely tiny and can only be seen after being magnified over 400 times. Spores can lie dormant indefinitely. Some guesses suggest that spores could lie without nutrients for millions of years. Mold spores have survived in ice, through fire, below water, and under immense pressure. A study was performed on mold spore germination from dormant spores as old as 25 years old. Even the oldest spores had a least a 95% germination rate (Cooke, 1993). There are seven steps of mold growth and creation:

1. Mycelium communities grow and mature,
2. Conidiophores grow from the mycelium,

3. Spores are released from the conidiophores and land in a nutrient-rich environment,
4. The spore germinates by growing in size, followed by the creation of germ tubes—small growths on the sides of the spore,
5. Germ tubes become longer and form additional limbs called hyphae,
6. Separations form, splitting the new network of limbs into segments, and
7. Once segments have divided the hypha into individual pieces, the new unit will continue to grow as mycelium (Cristensen, 1965).

If temperature, moisture levels, and nutrients are ideal, mold cells can grow very quickly, and as long as the conditions continue, the growth rate increases exponentially. "A moderately fast growing fungus will advance at the rate of about 1/8000 inch, or .00318 millimeters a minute. Each advancing cell will put out a new side branch of every thirty to forty minutes, and each one of these will advance at the same rate and produce new branches. In twenty-four hours a fungus colony such as this can produce a total length of over one-half mile, or .8 kilometers of mycelium, and in forty-eight hours will form a total length of hundreds of miles or kilometers of cells" (Cristensen, 1965). Figures 4 shows a conidiophore along with spores under a microscope slide and Figure 5 is an example of filamentous fungus or a network of hypha fibers used to sustain the mycelium.

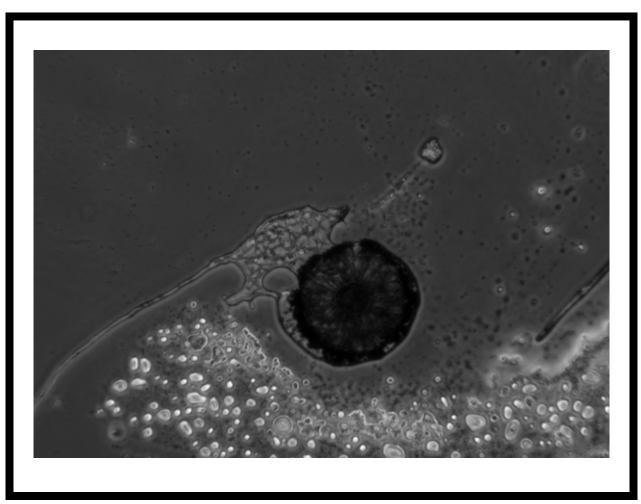

Figure 4. Conidiophore, flowering body with stem and bud, with spores below.

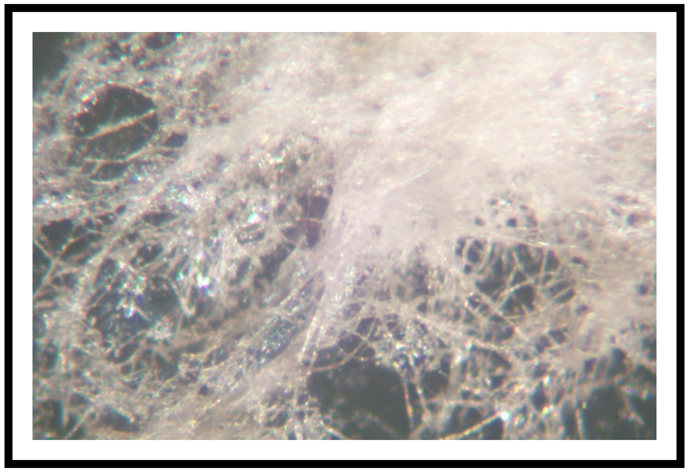

Figure 5. Filamentous fungus or network of hyphae.

Effects of Fungi and Mold

Fungi and mold and the spores they create can have numerous effects. Offhand, most people think of the negative connotations associated with these organisms, but they do have many good purposes too. Fungi have numerous roles in our daily lives. Bread rises with yeast, a fungi, and some medicines such as penicillin are also fungi. Fungi eat dead plants and animals, not only restoring necessary nutrients to the soil and making it possible for future plants and crops to grow, but also clearing room and space for new plants by removing the old. Fast growth and consistent behaviors have made molds useful in research for numerous health and science purposes, including fields in genetics, and biotechnology. Although fungi are essential for new life and growth, the same fungi can have deleterious effects too. Molds and fungi improve soil conditions, but they can also attack good crops, killing them before they can reproduce. Fungi can also be very poisonous.

Mold is becoming a bigger problem within homes and buildings due to fewer air exchanges, stemming from constant temporized interior air environments and a desire to conserve energy. Indoor areas provide an ideal environment for mold growth if moisture is introduced. Many infections and colds are now the result of these fungi. When fungi or spores cause infection or any type of harm to a host, it can be referred to as a pathogen.

Infections from mold fall into two general categories—obligate and opportunistic pathogens. As the name implies, opportunistic pathogens may be present on or within a person, but wait until the person's immune system leaves an opening or opportunity to attack. Healthy individuals are not at risk to opportunistic pathogens. However, obligate pathogens can be a danger to anyone. The human immune system, by way of helpful bacteria, skin, and mucus membranes, acts as a first line of defense against fungal attacks. The most common way for mold to attack humans is through the inhalation of microscopic spores into the respiratory system and lungs. This moist organic medium creates an ideal place for mold colonization. Once the mold begins to colonize and form mycelia, it can trigger numerous negative health effects ranging from minor fatigue and coughing to severe incapacitating colds (Oliver & Schweizer, 1999).

In addition to their pathogenic qualities, molds also create mycotoxins. Mycotoxins are produced by mold originating from the excreted enzymes or proteins during the digestion process. Mycotoxins can build up and even offgass as mycelium colonies grow large. Over 200 kinds of mycotoxins have come from mold. Some mycotoxins can be extremely toxic and can cause harmful effects on humans and animals if inhaled or ingested. Mycotoxins can also attack the kidneys, lungs, or be carcinogenic (Progovitz, 2003). Because of the negative effects of molds and their pathogens and mycotoxins, it is important to understand the ecology of mold. By doing so, it will be easier to appreciate mold in its proper place while being aware of personal environments and potential risk factors that could invite mold.

REVIEW OF LITERATURE:LIVING WITH MOLD

Introduction

Mold and mold spores are found everywhere, including inside homes and buildings. In the past 12 years, mold has become a very controversial and emotionally charged topic. During the mid 1990s a series of illnesses in Cleveland, Ohio known as the Rainbow Babies, drew attention to this issue. Numerous babies were having unexplained bleeding in their lungs, causing numerous additional side effects, many culminating in death. Dr. Dorr Dearborn found that the deaths were caused by mold—specifically *Stachybotrys* or black mold. Numerous cases of sudden infant death syndrome in the Cleveland area were then attributed to mold also (May, 2001). Nicholas Money, a mycologist and author of the book *Carpet Monsters and Killer Spores*, states in his preface that "Mold is a cash cow or buzz word for lawsuits." He begins his book with a quote from an internet site, "If you have found where you were exposed to toxic mold, you will need to find the responsible parties (if any) who are capable of paying" (Money, 2004).

Several high profile multi-million dollar cases around the United States also helped propel mold into the limelight, including Ed McMahon's $20 million suit and the case of Erin Brockovich, famous for winning over $300 million in a lawsuit over contaminated water in the Mojave Desert, who ended up buying a home in Los Angeles that required major mold remediation. Now, a simple search on the internet can bring up innumerable cases in any state in the U.S. A mental linear regression can be made by noting the number of mold cases handled by an insurance company in Texas--12 cases in 1999, 500 in 2000, and over 10,000 in 2001 (Money, 2004).

In reviewing mold within indoor environments, it is important to understand the health risks and implications involved with mold. In addition, it is necessary to know why mold grows and how to prevent it along with how to find mold and eliminate it if it does emerge in an indoor environment. An article entitled *Taking Up Residence* in the *Home Channel News* periodical discusses the need for coming up with a standard for mold growth. Since no definitive standards or regulations exist concerning mold, and due to a general fear of the unknown because of a lack of common knowledge of mold, numerous frivolous suits are taken to court. These cases can either be settled out of court to avoid high litigation costs, or they can be dragged through the court adding additional costs to the claims, which only exacerbates the media craze and lawsuit frenzy that is taking place (Canlen, 2002).

The EPA has several guidebooks and guidelines on moisture, mold, and mold remediation, but since no final authority on what is normal or standard exists, jurors are faced with the challenge of comparing facts and information about mold with heart wrenching stories and pictures. Although a voice of reason may be presented to a jury from field experts who have dealt with or studied mold, that voice lacks authority, leaving an open gate for lawsuits to continue to flood in and the precedents to amass against builders and suppliers. Lawyers may become a new required entity in home inspections and walk-throughs. A Pennsylvania family "demanded that a house be torn down and rebuilt with new lumber when mold was found growing on 50 studs". Later the builder found that the best solution would have been to clean the studs with bleach and water. It is important to understand how mold grows and reacts with different building materials, what effects this mold has, and what are the best solutions to respond to the mold (Canlen, 2002).

Health Risks and Side Effects

Concerns about indoor exposure to mold increase as the number of public court cases rises. Despite the rising public alarm, some believe that mold, the new money maker of lawsuits, is just an emotional myth that mold only affects the weak. Others hope that mold is just the current trend that will eventually fade away. Hopefully, as mold is studied, new construction and maintenance techniques can be practiced in order to alleviate the current mold burdens. Until then, it is important to understand side effects from living in an environment containing mold in order to distinguish myth from truth.

Mold, when introduced into a living environment, definitely has negative health effects to those exposed. The longer mold has the chance to grow, the more it will produce mycotoxins and spores that can cause allergic reactions and other negative effects. In fact, since mold growth is exponential, so are the amount of spores and toxins produced over time. The Cleveland, Ohio cases of babies exposed to Stachbotrys had severe effects including death, but revolved mainly around the respiratory system. Other negative health issues stem from touching or swallowing due to mold contaminated items or air. Although mold may have made its initial big debut in the Cleveland, Ohio case, documented mold problems have been around for a very long time. Stachbotrys mold had also been found to be the cause of death of a large number of Russian horses in the 1930's (Money, 2004). Additional research has been performed by the United States Army with mold toxins on human subjects to find possible hindering effects on cancer. Although the tests did not prove valuable in eliminating cancer, they did find direct evidence of the effects from inhalation through airborne particles, touch from particles and contaminated surfaces, and swallow exposure due to airborne particles landing on food, or being swallowed through the mouth or being swallowed from mucous connections from the nose of mold spores and toxins. The effects included "nausea, burning skin, confusion, lack of muscle coordination, slurred speech, and low blood pressure…diarrhea, dizziness, and central nervous system toxicity, which can lead to memory loss, lassitude, sexual dysfunction, vision impairment, and low blood pressure" (Rosen, 2006b).

People spend a majority of their time indoors and the quality of an indoor environment can have a large effect on not only a person's physical health, but their psychological health too. In addition to respiratory problems, headaches, allergies, and colds, poor indoor environments can cause moodiness, depression, and decreased learning capabilities or even diminished productivity levels (Rosen, 2006b). The side effects of mold have been studied and verified. Even the odors from molds can cause negative health effects. The odors contain chemicals called microbial volatile organic compounds or MVOC's, which are the cause of the musty smell of mold. These MVOCs can cause severe headaches, nausea, and additional respiratory problems (May, 2004).

Mold definitely causes a wide range of adverse health problems or symptoms depending on the amount of exposure and the individual. Luckily most effects are not long term and go away once the mold has been removed. Therefore, it is important to remove mold early on and to eliminate the environmental conditions that are favorable to mold.

Mold and Interior Environments

Mold thrives on any cellulose or carbohydrate based materials. Mold excretes enzymes onto these materials to break them down into an easily digestible glucose as a food source. Homes and buildings are filled with suitable breeding grounds for mold. Clothing, paper, furniture, and many building materials are loaded with cellulose, which when exposed to the right environmental conditions, become a host for a colony of mold. The most important environmental condition, moisture, is also already available in buildings and homes due to wet areas such as kitchens, bathrooms, and laundry rooms. Even the cleanest and most leak free homes probably show small visible signs of mold. If nothing else, the food in the refrigerator provides a moist cellulose or carbohydrate source for mold. Mold even grows on the tile and paint in the shower. The food source comes from biofilm, or a thin layer of microorganisms, floating carbon debris such as skin cells and dander, and bacteria that adhere to moist surfaces. This surface when left to grow is a rich source of nutrients for mold (Pascoe, 1999).

Although there are numerous building materials and items within a home that are conducive to mold, mold can not grow without moisture. Eliminating moisture should be the first priority in minimizing the risk of mold. Unabated water after 48 hours becomes an ideal breeding ground for mold. According to Gary Rossen, in *Locating Hidden Toxic Mold*, states "While indoor mold growth can be the cause of health problems, mold is not the cause of the building's problems. It is the moisture that is the source of the building problem. Indoor mold growth is an indicator of a moisture problem. Unless the cause of the moisture is properly solved mold will always return" (Rossen, 2006a). The EPA's draft for the *Moisture Control in Public and Commercial Buildings* outlines five steps for identifying either the cause or future causes for unwanted moisture infiltration:

1. Roof malfunctions
    - Flashing or poor edge joints
    - Ponding or improper drainage
    - Gutters and downspouts
    - Holes and overall damage
2. Landscaping
    - Porous materials next to sprinklers

- Slopes directing water toward a building
- Swales and drainage ditches are not clean and clear

3. Vapor moisture
    - Negative interior pressure near exterior doors
    - Negative pressure near wet areas such as showers
4. HVAC
    - Drip pans full of water
    - Outdoor intakes blocked or showing signs of rust
5. Plumbing
    - Signs of corrosion or leaks at valves or connections
    - Signs of condensation on piping or insulations
    - Cleanouts with debris
    - Moisture in or around faucets, tubs, sinks, cabinets
    - Signs of moisture behind or below washers and driers (U.S. Environmental Protection Agency, 2006).

Mold Testing

Mold can be tested in several ways. The three best and most simple ways to test for mold involve the human senses:

- Visual—black, gray, or colorful spots on drywall, paint, or tile, discoloration of carpeting or wallpaper, or any sign of water leaks
- Tactile—moist or wet areas in carpet, walls, ceiling tile
- Olfactory—musty, moldy, or unpleasant smells that do not go away in an area, or specific spot of carpeting.

These simple inspections are completed any time an area is inhabited, so as long as the occupants understand the background and warning signs of mold, mold can usually be found prior to any serious problems developing. Although these methods are definitely the first line of defense, these should not be relied upon completely if there are numerous cases of health issues arising from unexplained allergies or other symptoms. Again, mold must have moisture to grow. If there is no reason to suspect unwanted moisture, and if the above human sensory tests do not point toward mold, there is no reason to assume that mold is in a building or home. However, if cold symptoms cause an owner or a tenant to want additional proof, further tests may need to be performed. Before discussing the additional testing methods, if mold is visible and a moisture source is known, it is likely that further testing is not necessary. The EPA's guidance on remediation in school buildings responds to a common question of whether or not sampling is needed if mold exists (U.S. Environmental Protection Agency, 2006), "In most cases, if visible mold growth is present, sampling is unnecessary…only in specific instances should mitigation be used, such as cases where litigation is involved, the source of contamination is unclear, or health concerns are a problem." In addition to these reasons, if there is a question of the toxicity of the mold, it is usually best to immediately start the mold remediation process, assuming all molds have deleterious health effects, and normal remediation procedures and precautions should be followed.

Another type of sampling uses petri dishes and a nutrient rich base, usually agar, to grow mold. The mold can be collected by simply leaving the dishes exposed to the air for 20-30 minutes and then closed and placed in a mold friendly environment to see what grows. However, this only captures airborne spores. Although in most cases this test should be a good representation of the types of spores, some molds such as those in carpets or other areas may only become airborne when disturbed by walking over or brushing against the area. Another example could be mold growing on the underside of a drawer. The particles would only become airborne when the drawer is opened and closed. Swab tests with a Q-Tip inside air conditioning ducts or tape tests on furniture and different surface areas can provide additional collection methods for mold growth. However, collecting these samples alone is not an acceptable diagnosis for mold. Just because the spores exist inside a living or working area does not necessarily correlate the presence of active growing mold. Water has to exist for mold to appear.

Although many environmental conditions can affect airborne spore counts, air sampling is extremely useful for defining a baseline to define what a normal amount of airborne mold particles should be. What is "normal" depends highly on the locality and time of year for the testing. Spore levels outside may be very high in the spring, but low in the winter. A light breeze or a recent rain fall can also change the amount of spores in the air. Rain can initially lower spore counts, but often they increase shortly after due to new growth of fruiting bodies, causing more spores and creating a new moisture supply for different molds. If the mold has not been disturbed, spores may have settled onto surfaces, giving a low spore count in the air, showing the need for some swab and surface sampling (Pascoe, 1999). Air sampling also does not distinguish what type of particles are in the air or if the air particles are even mold spores unless the particles can be trapped and removed from the air and then tested in a lab. However, air sampling is a great way to establish a baseline for the amount of particles that should be in the air based on other outdoor and indoor mold particle counts. If the indoor particles greatly outnumber the outdoor count based on time of year and environmental conditions, then a problem may exist. Although some air quality meters can distinguish different types of particulates, or can collect air particles for testing, others combine all airborne particles in the count, so dust, pollen, and other particle air pollutants should be taken into consideration. Last, numerous variables could influence air particle testing results. Gusts of wind or recent mold disturbances could cause spikes in results.

No one way is best for testing an indoor area for mold. Human senses certainly make the best detection senses due to regular testing, cost, and early detection. Lab samples are the best method of sampling to determine mold type, but do not detect a mold problem. Air sampling is great for establishing a baseline and is also best when combined with other testing methods (Finsand, 1989, and Black, 2006).

Mold Assessment and Remediation

Mold is extremely versatile when it comes to growing in different environments and conditions. However, since mold thrives in certain environmental conditions it is important to take care of these first. The following is the list of environmental conditions, followed by the simple solution that should take place prior to any in-depth remediation:

- Temperatures ranging from 70 to 90 degrees Fahrenheit are just right for optimal mold growth. Try to open windows for ventilation and lower the temperature without running a central heating or cooling system in order to minimize the transfer of mold spores through duct work.

- High humidity or water is necessary for mold growth. The first step in remediation should be to verify that the source of the water has been stopped. Next, any standing or visible water needs to be removed. Water sitting for longer than 48 hours can greatly increase the chances for mold growth. Water should first be removed by mechanical means such as wet/dry vacuums or carpet cleaners, and then fanning and ventilation should be used to speed up remaining evaporation. Any humidity level higher than 50 percent is also an ideal condition for mold. Dehumidifiers can be employed to reduce moist air.
- Air should not be stagnant or dark when possible during remediation. Open outside windows when possible for light and for natural ventilation. Use fans or blowers to move air around corners and in tight spaces. This also helps remove the moisture.

Once this is complete, a plan should be made for mold removal. The plan will depend on how many and what kind of areas are contaminated. The Occupational Safety and Health Website's workplace mold guide provides general guidelines on determining the size of a remediation project:

- **Level I: Small Isolated Areas** (10 sq. ft or less) - e.g., ceiling tiles, small areas on walls,
- **Level II: Mid-Sized Isolated Areas** (10-30 sq. ft.) – e.g., individual wallboard panels,
- **Level III: Large Isolated Areas** (30 –100 square feet) – e.g., several wallboard panels, and
- **Level IV: Extensive Contamination** (greater than 100 contiguous square feet in an area)" (U.S. Department of Labor Occupational Safety and Health, 2007).

Anything larger than 30 square feet may require additional investigation and potentially professional advice or help due to the possibility of a larger hidden problem. Also, a job larger than 30 square feet can have major and further negative consequences due to errors and improper removal techniques. If the contaminated area or the area of visible mold is small, a simple solution of bleach and water can be used to remove the mold. Bleach at a concentration of one cup per gallon should be sufficient to kill any existing mold. Porous surfaces may be harder to clean depending on how deep the mold has penetrated. If the bleach is not able to contact the mold, it can not kill the mold. In this case, if the porous material continues to have a musty odor or if mold begins to reemerge, it may be best to remove and replace the surface or item. Besides using bleach, there are numerous fungicides on the market that claim different mold killing properties. Some suggest that bleach cannot or will not kill mold. This is not true. Other fungicides claim to be a permanent solution to mold. Unfortunately, if the environment continues to be favorable to mold growth, mold will return. Next, there are some health concerns due to inhalation and skin exposure that should be researched prior to using any product for mold remediation. Some products have serious side effects from inhalation that will require respiratory protection, and most require gloves and skin protection. Bleach, although it is very affordable and found in homes already, should also be used with caution, proper ventilation, and respiratory and skin protection due to harmful effects from concentration. If the area is large, a more detailed plan will need to be laid out. Some or all of the following may need to be accomplished, assuming that the earlier preliminary steps have already been accomplished:

- Ductwork and non-contaminated areas sealed off to avoid spreading of additional spores,
- Create a negative pressure area to the outside of space,
- Porous materials such as carpet, carpet pads, rugs, may need to be removed/replaced,
- Books and papers may need to be saved despite mold contamination; these items can sometimes be left outside, ideally exposed to dry moving air and lots of sunlight,
- Furniture and belongings may need to be removed and sanitized,
- Interior wall spaces may need additional inspection via probes/small destructive testing,
- Wallpaper and even drywall may need to be removed,
- All areas will need to be sanitized with bleach and dried prior to reassembly,

- Ducts cleaned prior to bringing back furniture and belongings and,
- Additional air quality tests should be compared to baseline and initial tests to show improvement (U.S. Department of Labor Occupational Safety and Health, 2007; Rosen, 2006c).

When accomplishing mold removal work, especially if any of the mold was tested and found to be toxic, it is important to practice safe work habits. Mold spores and mycotoxins can spread anywhere, so it is important not only to breathe filtered air via a mask or respirator, but also cover personal clothes that may come in contact with other interior areas or others. This can be done with simple disposable suits, taped at joints to eliminate taking unwanted mold to other areas. Finally, goggles or eye protection will provide an additional barrier between your eyes and airborne particles caused by mold (Rosen, 2006c).

When completing a mold assessment, it is important to not overlook the areas that can not be seen. If the contaminated area is small, simple visual, tactile, and olfactory tests of the carpet, wall paper, and cabinet areas may suffice. If any of the areas smell musty, moist, or have an off color, such as a grayed out spot that will not clean off of the wall paper or carpet, or if the contaminated areas are large as defined earlier, additional testing will be required. Since mold does not do well with direct sunlight, mold often will grow behind the wallpaper, drywall, or carpet areas. Carpet is the easiest to inspect below. Carpet can be pulled away from the wall and examined visually for signs of mold, tactilely for wetness, and olfactorially for musty odors. Carpet pads are typically glued down and only the first few inches of the edge can be lifted. If any signs of mold are found, all of the carpet may need to be removed or cleaned depending on the severity of the mold. Wallpaper is also glued down, so a corner behind a cabinet or toilet area or an inconspicuous place is a good starting point. All of the paper should be removed if signs of mold are found. Visual signs on the outside surface of drywall without any obvious signs of moisture or simple solution to ending the moisture should signal some drywall removal. Penetration-type moisture meters can be used to determine the moisture levels within wall materials or drywall. In addition, relative moisture meters can be used to scan walls to find wet spots or areas that have more moisture than others. Lastly, moisture meters or humidity meters equipped with a probe can be used by drilling holes in walls in order to avoid complete drywall removal. Ultimately, the drywall and insulation should be completely removed if moisture or mold has been found within the wall cavity. The EPA's *Mold Remediation in Schools and Commercial Buildings,* outlines cleaning steps for different types of materials:

- Books and papers—discard and replace unneeded items; freeze and clean valued items,
- Carpet—dry within 48 hours; dehumidify area; fan dry,
- Ceiling Tiles—discard and replace,
- Cellulose Insulation—discard and replace,
- Concrete/cinder block—vacuum dry; additional fan dry,
- Fiberglass insulation—discard and replace,
- Hard surface flooring—dry and clean with bleach; check subflooring,
- Non porous items and surfaces—dry and clean with bleach solution,
- Upholstered furniture—vacuum dry; fan and heat dry; dehumidify,
- Drywall—if swelling exists destroy and replace; dry with fans/dehumidification if no swelling; test for moisture behind wall with meter and probe,
- Drapes—launder if possible and,
- Wood surfaces—paneling should be removed from walls; clean with detergent, (spot check for staining), dry with fans, gentle heat, and dehumidification (U.S. Environmental Protection Agency, 2006).

Mold Description

Mildew is often mentioned as an indoor nuisance that grows on wet areas of tubs, tiles, behind furniture and even on furniture and is typically black, white, or grayish in color. Although the words are often used interchangeably, mildew is a plant disease and is just a type of mold when growing indoors. The mold will belong to one of many types of molds: *Cladosporium*, *Penicillium*, *Aspergillius*, *Alternaria*, *Stachybotrys*, and *Chaetomium* are just a few of the common types. Appendix B contains a picture guide of over sixty commonly found species of mold! The picture guide also includes a spot for bacteria since mold and bacteria typically enjoy the same environments.

One of the most famous types of mold and the cause of the new scare crazes due to its very harmful effects is *Stachybotrys* which is often called the black mold. This does not mean that all black molds are *Stachybotrys*. In fact, the majority of molds are black or are dark in color. Even though *Stachybotrys* is listed with the common molds, the chances of a black mold being *Stachybotrys* is not likely. Some black molds even grow in similar places and patterns as *Stachybotrys*. Numerous types of mold often grow on thin layers of dust, dust mites, or residue layers called biofilm found on shower walls and curtains, near sinks, stoves, and other hard surface contaminated areas. These molds, although they should be cleaned up as quickly as possible, typically give off very little amounts of allergens or mycotoxins and are nearly harmless to most people. Fortunately, black fuzzy mold in circles, patches, or films of mold on drywall is not necessarily a sure sign of "the" famous black mold or *Stachybotrys*. The mold could be one of many species including *Chaetomium* which also loves drywall. In fact, several of the species have a strong earthy musty odor and often look similar to *Stachybotry*, but when grown in a lab environment appear to be green. *Chaetomium* molds can cause allergic reactions in children and have plenty of negative health effects, but are still not the black mold referred to in the media.

Another common indoor mold is *Penicillium* which can attack even the cleanest of households. *Penicillium* grows in colder climates, and is found in refrigerators on forgotten leftovers or on the bread on the counter. *Penicillium* has numerous uses and is low as far as toxicity, but should not be eaten or allowed to grow in indoor environments due to spore production and the transportation to areas that are not food. *Penicillium* is not just limited to food for growth and is sometimes diagnosed as the "mildew" on baseboards or on furniture in homes.

Another colorful mold variation is Blue Stain, named due to its bluish color. It does not usually grow well on cellulose and prefers wood, but is not a major threat to wood like the different types of mold that cause brown-rot, commonly called dry-rot and white-rot. The mold digests the wood, causing structural damage to a building. Brown-rot only digests the white cellulose in the wood, leaving the brown lignin behind as a dry crumbly waste. Hyphae transport water for the mold colonies to move to the leading food edge. White-rot mold is able to digest all of the wood and is sometimes simply diagnosed as rot when the ends of studs or wood members are missing.

Wherever the rot or mold is coming from, the only sure way to identify a type of mold is under a microscope. The individual conidiophores must be isolated and examined. Prior to being examined, molds often need to be cultured in a lab from spores removed from a site due to the delicate nature of the conidia. A slide can easily crush the individual flower blossom of the mold, making it nearly indistinguishable from other conidia as seen in Figures 6 and 7: conidiophores are much easier to distinguish when they are viewed without being removed from their medium.

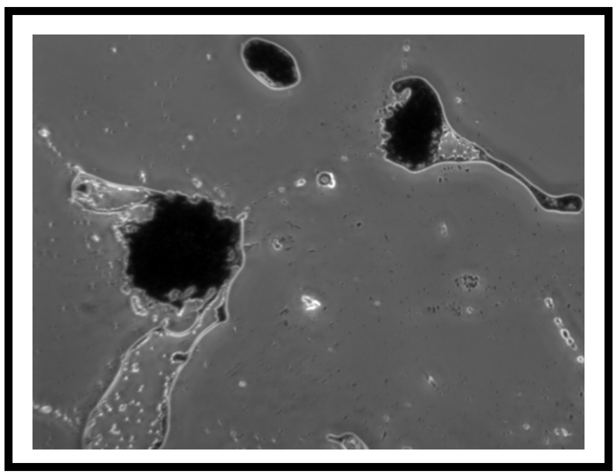

Figure 6. *Aspergillius* conidiophore under slide—400 times magnification.

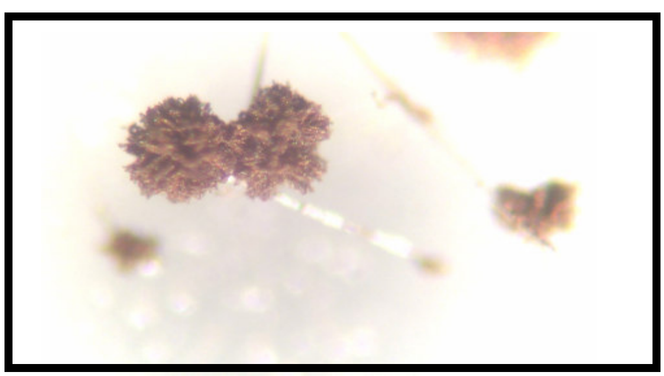

Figure 7. Conidiophore of *Gymnoascus* mold—400 times magnification.

Many molds are similar in color, can cause similar musty earthy smells and odors, and all will digest a facility in the presence of unwanted moisture. However, it is important to reiterate that not all molds are toxic or fall into the media scare of "black mold". This is a convenient description for the promulgation of mold litigation cases since conveniently the majority of molds are black in color. Molds actually offer a small benefit in the fact that they can act as a signal that a moisture problem exits. Equally, it is important to reemphasize that all molds are producing spores and are not conducive to a healthy living environment. In addition, many are digesting a building or home and should be removed as soon as possible (Black, 2006 and May, 2004).

METHODOLOGY

Experiment Setup

The study was going to start with a 30 day Beta test to see if any mold would grow on a set of four selected rapidly renewable materials, to include wool, cork, straw, and cotton, to ensure the test did not need other parameter changes. If the mold mycelium began to produce, the 30 day study would continue for an additional 60 days. If no mycelium was present, then the test was reviewed to determine other possible methods for measurement or testing. The decision to stop the tests following the initial 30 day test was made because of unexpected speed and amount of results. The test examined the four rapidly renewable materials for their susceptibility to mold growth. These materials were selected because they are all commonly used as building insulation products, both by themselves and combined with other recycled materials such as paper. The four above mentioned materials were acquired in their pure form, not combined, enhanced, or modified by other materials. The materials were left outside on a pallet for five days to simulate realistic exposure to mold spores and the environment prior to installation at a construction site—covered from rain but exposed to other elements such as temperature, dust, and humidity. This is representative of industry practices for materials to be delivered early and then covered until installed. Each material was then cut/assembled into three by four inch sections or near equivalents in the cases of straw and cotton, and placed into a 32 ounce, or approximately 950 mL, clear plastic jar with a screw-type lid—see Figures 11-22 on pages 40-43. Each material was placed into nine jars. The jars simulated the encapsulated wall environment—stagnant encapsulated air with the absence of direct sunlight. A third of the jars contained a material along with 75 milliliters of water, 25 milliliters of water and no added water—see Figure 8 for a graphic example. Moisture was obtained from tap water and measured with a sterile flask. Tap water was used to be more realistic of a leaky pipe or water infiltration. The jars were separated into three groups, but kept under identical conditions. Three groups were used in order to increase the number of degrees of freedom or data points, thus increasing overall validity of the test results.

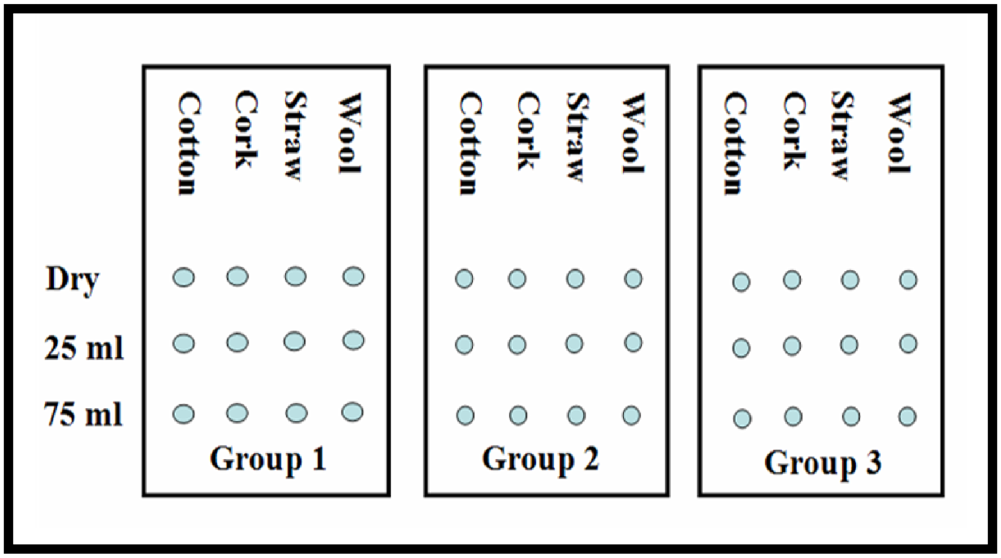

Figure 8. Three sets of four materials and three moisture amounts.

The jars were to be examined for the amount of mold growth coverage every three days. However, due to the speed and amount that the mold started growing, results were taken on day one and every other day up to day 31. The amount of mold growth was recorded by measuring the area covered by visible mycelium on each side of the material and then estimated as a percentage of coverage over the entire piece of material. A magnifying glass was used to examine each side of the material for mycelium. The mycelium from each side of the material was then sketched onto sheets of engineering paper in order to estimate the percentage of mold coverage. Each set of experiments was also monitored with data loggers to determine temperature and humidity levels throughout the experiments. At the end of 31 days, the moisture meters were removed.

Statistical Model Setup

Following the experiment the data for the 31 days was going to be compared and analyzed with the use of SPSS, a statistic software package, and specifically, in addition to descriptive statistics, a three factor ANOVA model with a repeated measures design was going to be used to test the three null hypotheses to include:

Ho: all of the materials = zero mold over time,

Ho: moisture levels = zero difference in mold growth, and

Ho: all materials will act alike, wool = cork = straw = cotton.

The three factors were to include material type, moisture amount, and time shown in Figure 9. However, because the time frame turned out to be so short, the time factor with repeated measures was not necessary. The samples were all watched until they reached 100% coverage. The number of days taken to reach 100% covered by mold became the dependent variable and a more simple two factor ANOVA, (mold = mu + ma(j) + mo(k) + error), was used to analyze the results. Figure 9 shows the original time series model to be used for analyzing data, (the i, j, and k in the model stand for the multiple categories within a variable.

$$\text{Mold} = \mu + r_i + ma_j + mo_k + (ma*mo)_{jk} + \text{error(a)} + time_l + (ma*time)_{jl} + (mo*time)_{kl} + (ma*mo*time)_{jkl} + \text{error(b)}$$

r = rep

ma = material

mo = moisture

time

Figure 9. Statistical model for mold growth over time.

Mold Isolation and Identification

After the necessary portions of the testing, additional experiments followed to determine the different mold types within the samples. The samples were taken to a biology lab, and swabs were use to isolate individual molds into separate Petri dishes. Slides were then made from the Petri dish growths and placed under a microscope in order to identify the different types of molds growing on the different rapidly renewable materials.

ANALYSIS OF DATA

Collected Data

After 31 days, the tests were stopped due to two reasons. First, due to the speed and significance of the mold growth, nearly all materials were 100% covered. Second, several of the data loggers had stopped taking measurements for temperature and humidity. On day 31 the final measurements were taken on all samples. However, the seven samples that had not reached 100% were still monitored regularly to determine the date that the materials were completely or 100% covered by mold. Initially due to the length of time these samples were planned to be observed, time series analysis was going to be used to interpret the statistics in an effort to create a linear growth model of mold over time. However linear models were not necessary due to the speed of the mold growth. Figures 10 to 21 are pictures taken of the different materials and moisture amounts at day 35 following the collection of data, followed by Table 3 which shows all of the data gathered during 31 days.

During the test, wool with moisture in Figures 10 and 12 was quickly covered with filamentous fungus or hyphae networks. In addition, the samples formed dark gray mycelium, some producing red droplet by-product throughout. The cork, Figures 13 – 15 grew a thick covering of black mycelium, which quickly reached even the driest corners of the material. Following, green mycelium also began to emerge on the edges and bright yellow fruiting body-like structures started appearing in large clusters. The straw, Figures 16 – 18, had a variety of green, black, gray, and white mycelium along with clusters, patches, and webs of filamentous fungus. The cotton, Figures 19 – 21, only had small dark black specs that appeared in patches. The patches took longer to appear initially, and spread more slowly than the other molds on the other three materials.

Following the photos of the four sample materials is Table 3. This table shows all of the results of the data collected during the first 31 days. The data chart shows the materials used, amount of moisture in mL, and the percent of the material that is covered by mold. The highlighted areas show samples that had surpassed the 100 percent coverage point.

Figure 10. Wool with 0 mL of water after 35 days.

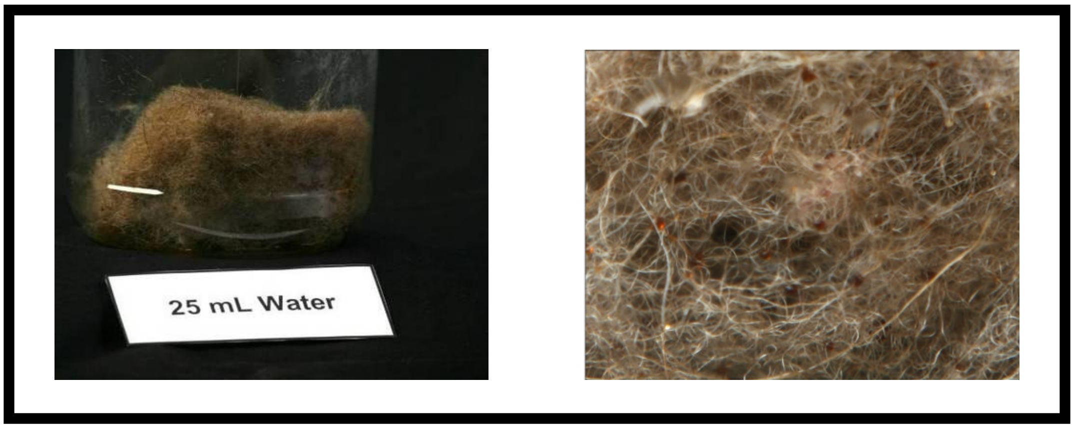

Figure 11. Wool with 25 mL of water after 35 days.

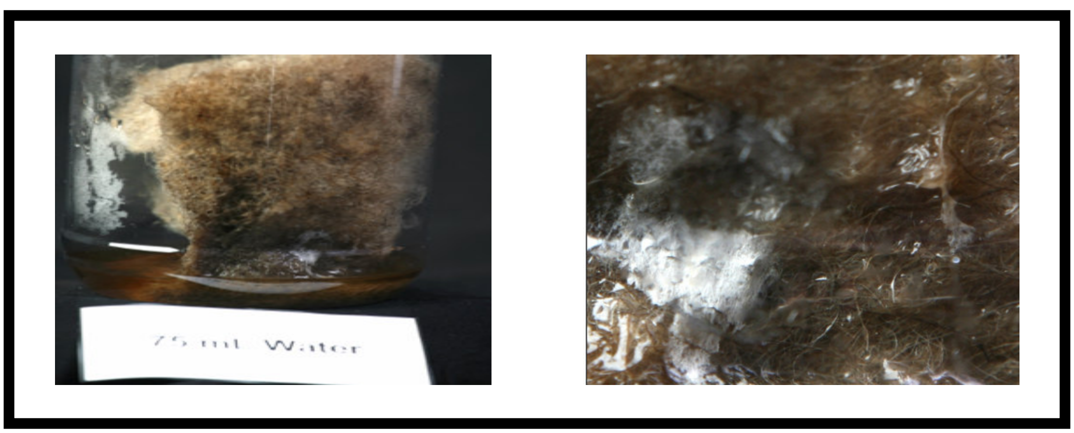

Figure 12. Wool with 75 mL of water after 35 days.

Figure 13. Cork with 0 mL of water after 35 days.

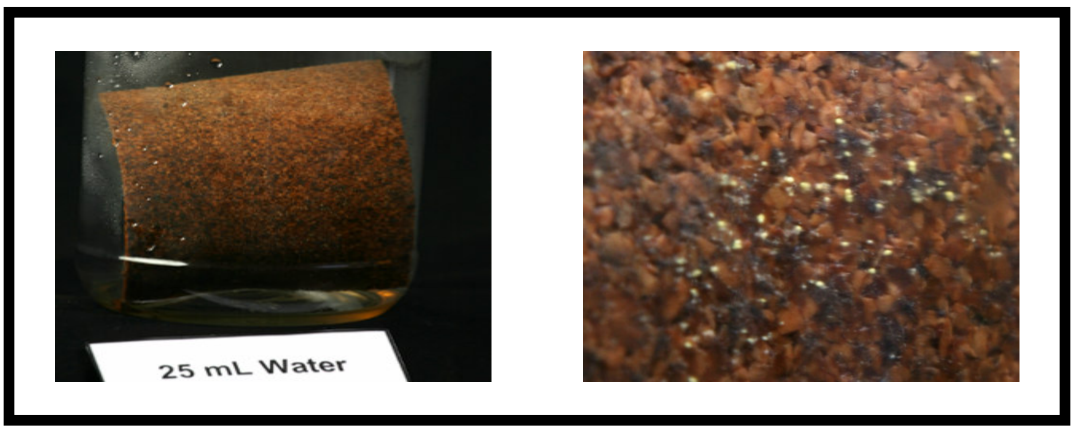

Figure 14. Cork with 25 mL of water after 35 days.

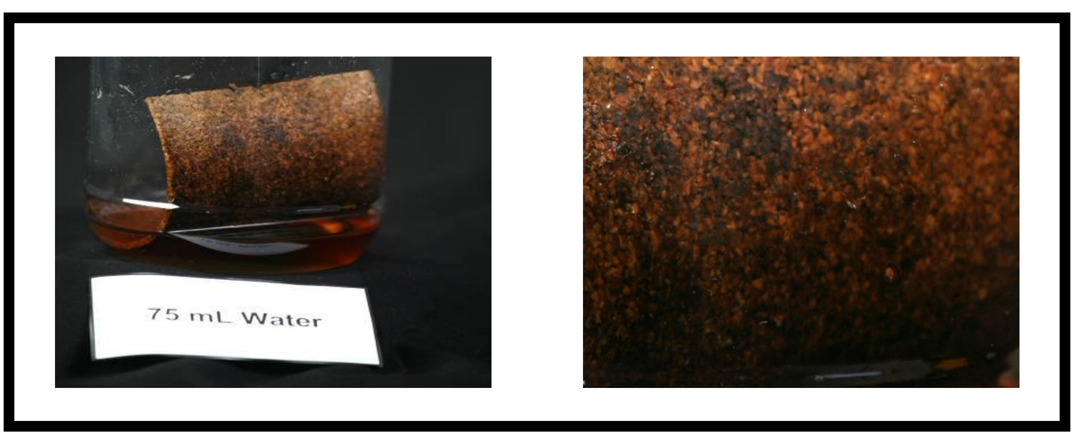

Figure 15. Cork with 75 mL of water after 35 days.

Figure 16. Straw with 0 mL of water after 35 days.

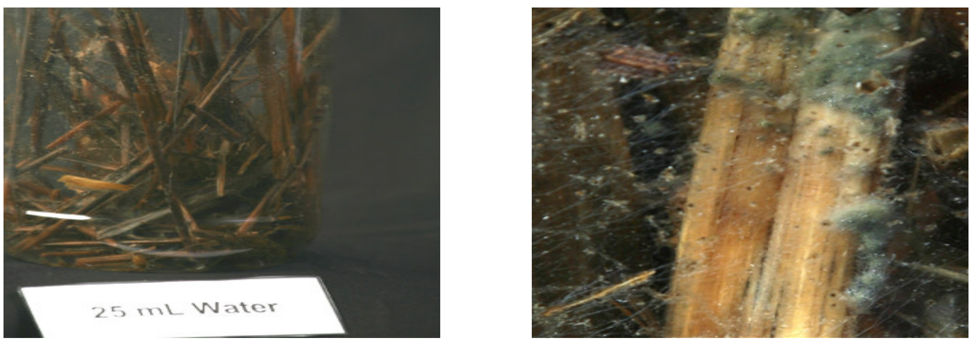

Figure 17. Straw with 25 mL of water after 35 days**.**

Figure 18. Straw with 75 mL of water after 35 days.

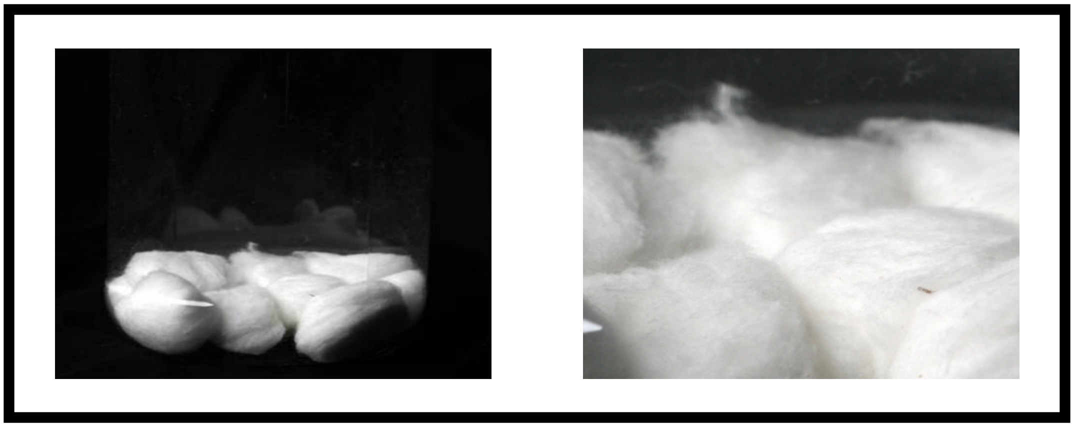

Figure 19. Cotton with 0 mL of water after 35 days.

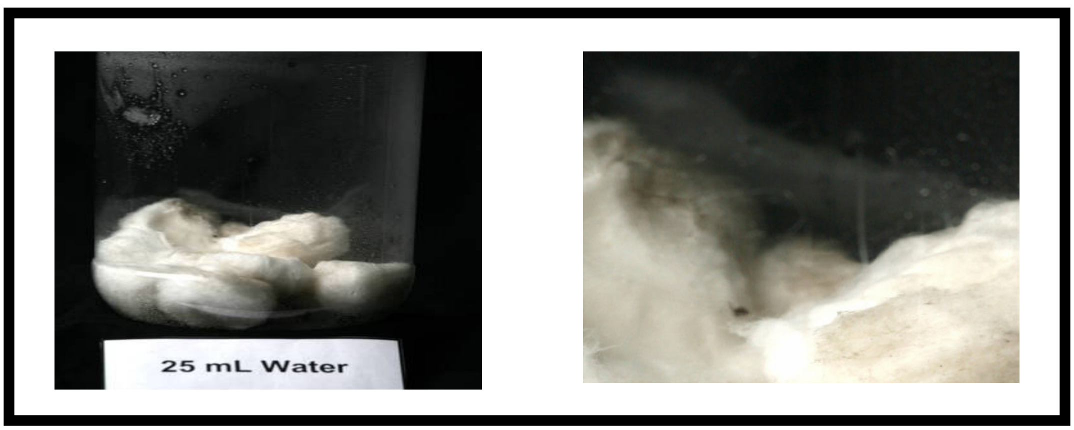

Figure 20. Cotton with 25 mL of water after 35 days.

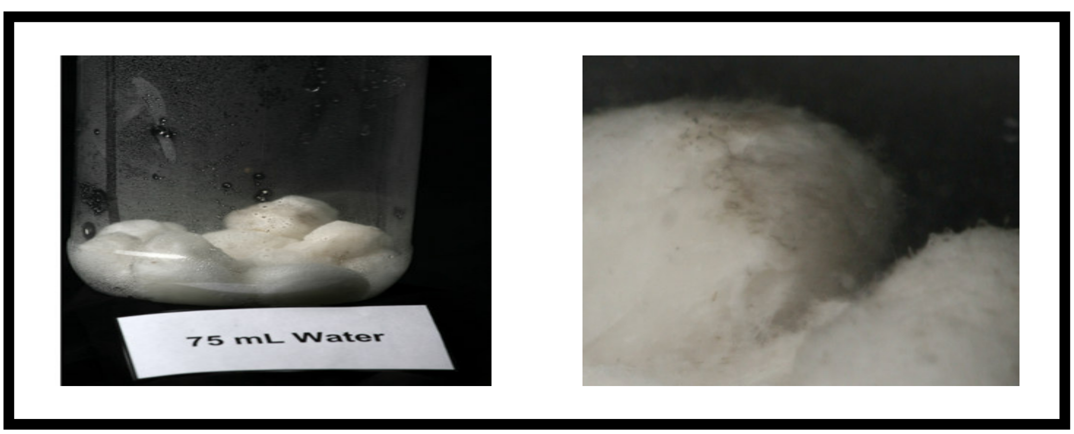

Figure 21. Cotton with 75 mL of water after 35 days.

Table 3. Material, moisture amount, and percent coverage by mold, days 1-31.

		Day															
Mat.	**Water**	**1**	**3**	**5**	**7**	**9**	**11**	**13**	**15**	**17**	**19**	**21**	**23**	**25**	**27**	**29**	**31**
cotton	75	1	5	10	20	20	20	25	25	30	35	40	40	45	45	50	50
cotton	75	1	5	10	10	10	10	10	15	20	25	30	30	35	45	60	65
cotton	75	1	5	10	10	20	20	20	25	30	30	30	30	30	35	35	45
cotton	25	0	5	10	10	10	10	10	10	10	15	20	20	20	20	20	25
cotton	25	1	5	10	10	10	10	10	10	10	10	25	15	15	15	15	25
cotton	25	1	5	10	10	15	10	20	30	30	30	35	35	35	35	35	45
cotton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cotton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cotton	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
wool	75	10	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100
wool	75	20	25	80	100	100	100	100	100	100	100	100	100	100	100	100	100
wool	75	10	20	80	100	100	100	100	100	100	100	100	100	100	100	100	100
wool	25	10	50	100	100	100	100	100	100	100	100	100	100	100	100	100	100
wool	25	20	25	75	100	100	100	100	100	100	100	100	100	100	100	100	100
wool	25	10	20	80	100	100	100	100	100	100	100	100	100	100	100	100	100
wool	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
wool	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
wool	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cork	75	20	60	80	80	80	80	80	80	85	90	95	100	100	100	100	100
cork	75	25	60	80	80	80	90	95	100	100	100	100	100	100	100	100	100
cork	75	25	60	80	80	85	85	90	95	100	100	100	100	100	100	100	100
cork	25	20	60	80	90	95	95	95	100	100	100	100	100	100	100	100	100
cork	25	25	60	80	80	85	90	95	100	100	100	100	100	100	100	100	100
cork	25	25	60	80	90	100	100	100	100	100	100	100	100	100	100	100	100
cork	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cork	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
cork	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
straw	75	0	0	0	0	1	1	5	5	10	15	30	35	35	40	45	70
straw	75	10	20	15	15	80	90	100	100	100	100	100	100	100	100	100	100
straw	75	1	5	15	100	100	100	100	100	100	100	100	100	100	100	100	100
straw	25	0	1	5	5	80	80	80	80	80	85	85	100	100	100	100	100
straw	25	0	0	5	5	10	15	15	35	40	50	80	80	80	80	80	100
straw	25	1	10	50	90	100	100	100	100	100	100	100	100	100	100	100	100
straw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
straw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
straw	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Data Review

Although the data was not logged after 31 days, the samples continued to be inspected to see when the materials ultimately hit 100% coverage. Table 4 shows all of the material samples sans the control group, followed by the amount of moisture added to the sample in mL, and the number of days that it took to be 100% covered by mold (note, the number to the left of each material is the material code later used in SPSS computer program for review statistics).

Table 4. Number of days for 100% mold coverage on individual samples.

Material	Moisture	Mold Coverage Time
1 Wool	75 *mL*	5 *Days*
1 Wool	75 *mL*	7 *Days*
1 Wool	75 *mL*	7 *Days*
1 Wool	25 *mL*	5 *Days*
1 Wool	25 *mL*	7 *Days*
1 Wool	25 *mL*	7 *Days*
2 Cork	75 *mL*	23 *Days*
2 Cork	75 *mL*	15 *Days*
2 Cork	75 *mL*	17 *Days*
2 Cork	25 *mL*	15 *Days*
2 Cork	25 *mL*	15 *Days*
2 Cork	25 *mL*	9 *Days*
3 Straw	75 *mL*	35 *Days*
3 Straw	75 *mL*	13 *Days*
3 Straw	75 *mL*	7 *Days*
3 Straw	25 *mL*	23 *Days*
3 Straw	25 *mL*	31 *Days*
3 Straw	25 *mL*	9 *Days*
4 Cotton	75 *mL*	76 *Days*
4 Cotton	75 *mL*	72 *Days*
4 Cotton	75 *mL*	79 *Days*
4 Cotton	25 *mL*	69 *Days*
4 Cotton	25 *mL*	57 *Days*
4 Cotton	25 *mL*	65 *Days*

The data loggers collected information on relative humidity and temperature. The relative humidity for all samples with moisture added stayed steady near 100%, see the top even line in Figure 22. The temperature mainly stayed between 70 and 85 degrees, but went as low as 55 degrees and as high as almost 90 degrees, (21.44, 29.44, 12.77, and 32.22 degrees Celsius respectively), making the conditions inside the encapsulated environment ideal for mold growth.

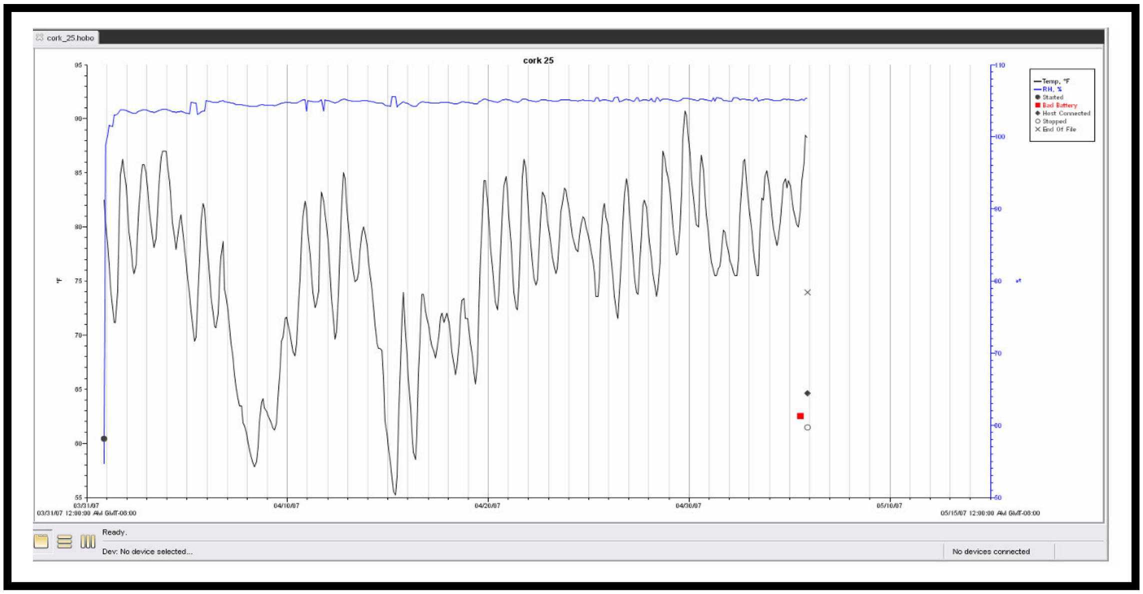

Figure 22. Data logger temperature and humidity measurements.

Figures 23 – 26 graph the rapid progression of the mold. The mold flourished on the materials, showing extremely aggressive growth trends for both wool and cork. By day seven, all of the wool samples containing moisture were covered with visible mold growth, and the cork samples were showing similar results. The straw and cotton were slower showing visible signs of mold initially. By day 35 all of the straw samples containing moisture were completely covered by visible mold growth.

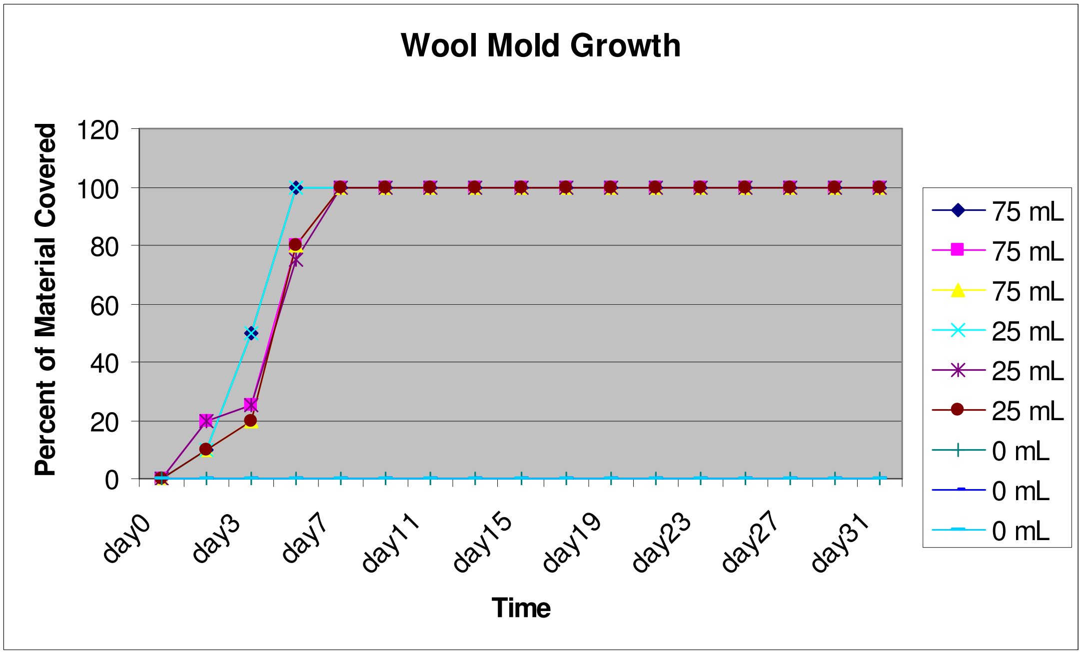

Figure 23. Recorded mold growth patterns for wool.

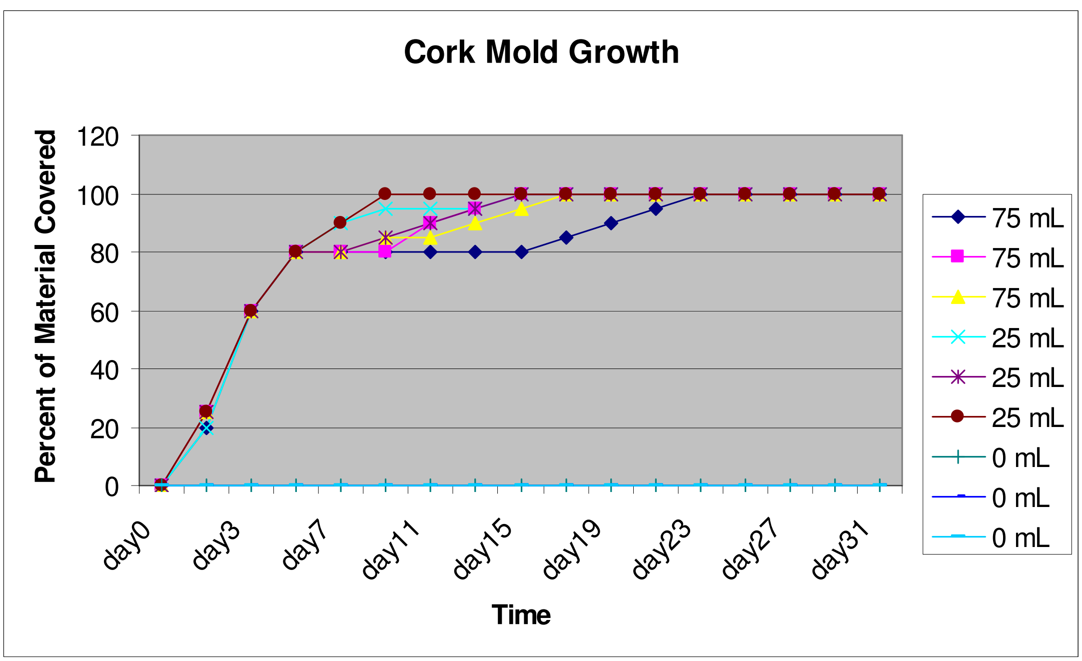

Figure 24. Recorded mold growth patterns for cork.

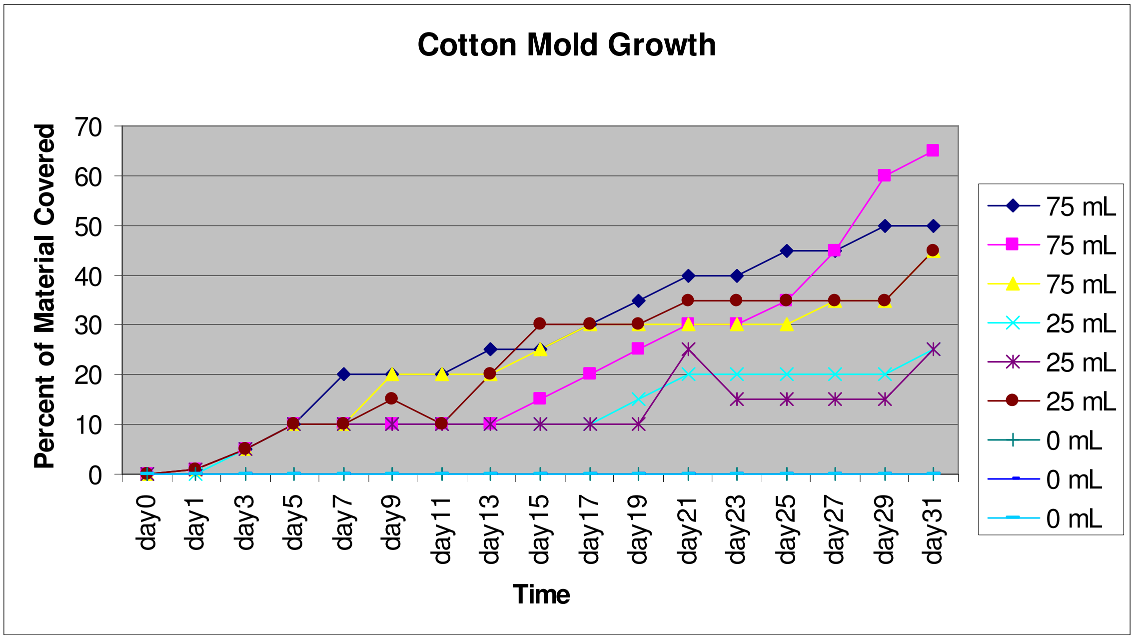

Figure 25. Recorded mold growth patterns for cotton.

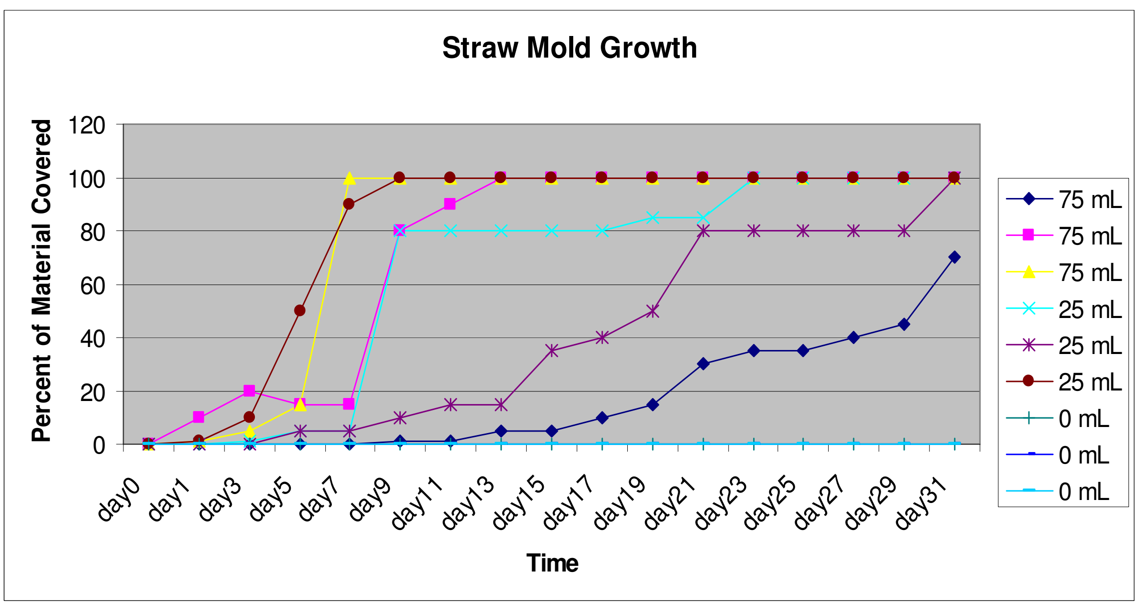

Figure 26. Recorded mold growth patterns for straw.

Figure 27 is an initial visual comparison of the amount of mold growth due to the amount of moisture only. Figure 27 is a box plot that shows mold growth averaged among all materials through each day of the experiment. A box plot is a graphic depiction of descriptive statistics including the smallest observation or the lowest horizontal line, the largest observation shown by the top most horizontal line, the median or central data point shown as a line inside the box, and the upper and lower quartile data which is demonstrated by the box. The box plot, with the exception of the highest and lowest point, illuminates the central data and the median point, focusing on the middle data and ignoring outliers. Box plots are a simple and easy way to observe patterns within data, including skewness of populations, comparing variances, and medians. By showing a time series of box plots, observations of the movements of data and medians can be seen over time.

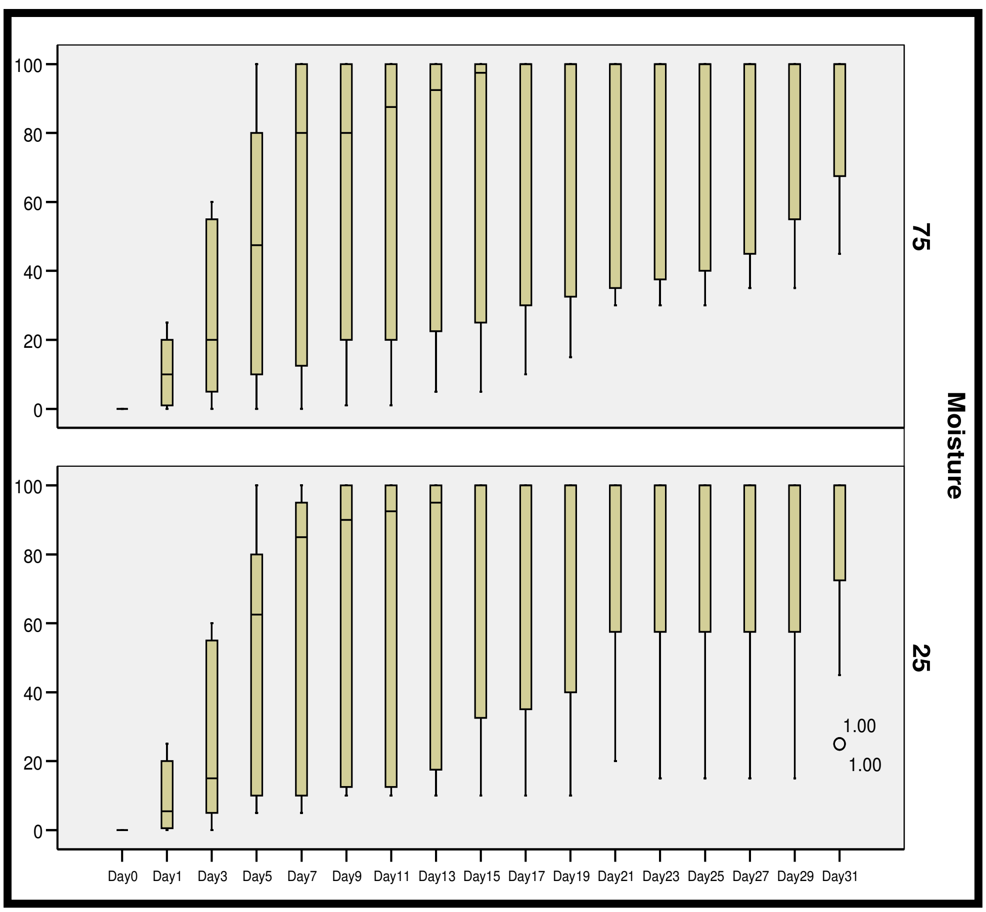

Figure 27. Box plot comparisons of average mold amounts for each day recorded.

Figure 27 shows common patterns between the two moisture amounts and mold growth. The median mold amounts are also very similar, moving past 100% coverage by 15 to 17 days. From the visual display of data, it appears that the amount of moisture in this study did not make a significant difference in the rate of mold growth.

Statistical Analysis

Having examined the trends for mold growth for each material, the data was input into SPSS, a statistics program, to further evaluate trends and to test the original three null hypotheses which included:

- Materials would not grow mold,
- Moisture will not make a difference in mold growth, and
- Materials will all react the same.

The numbers 1 – 4 were used in the place of wool, cork, straw, and cotton respectively. Table 5 shows the mean and standard deviations for the percent of mold coverage on each material. The means show similar trends to the graphs in Figures 23 – 26 earlier. Interestingly, the standard deviations do not show a lot of variation between materials with the exception of straw. A possible reason for this may be the matrix or homogeneity of the materials. The wool, cotton, and cork samples were all pretty homogenous, whereas the straw was a mixture of shafts and leaves with varying lengths within.

Table 5. Descriptive statistics for materials and moisture groups shown in mL.

Descriptive Statistics

Dependent Variable: moldcoverage

Moisture	Material	Mean	Std. Deviation	N
25.00	1.00	6.3333	1.15470	3
	2.00	13.0000	3.46410	3
	3.00	21.0000	11.13553	3
	4.00	63.6667	6.11010	3
	Total	26.0000	24.02272	12
75.00	1.00	6.3333	1.15470	3
	2.00	18.3333	4.16333	3
	3.00	18.3333	14.74223	3
	4.00	75.6667	3.51188	3
	Total	29.6667	28.99634	12
Total	1.00	6.3333	1.03280	6
	2.00	15.6667	4.50185	6
	3.00	19.6667	11.77568	6
	4.00	69.6667	7.94145	6
	Total	27.8333	26.10791	24

A two factor ANOVA, or analysis of variance, in SPSS was used to examine the hypotheses stated earlier. The ANOVA table was used to answer the last two hypotheses of whether the materials would react significantly differently and if the amount of moisture had a significant effect on the growth of mold, using .05 as a standard alpha level in order to determine significance. The significance of moisture amount within the context of this study is .235, and the potential for interaction and the material is .345, making neither possibility significant. However, material differences show a significance value of .000 making it well below or within the value range for significance. Another useful piece of information from the ANOVA table is the R Squared or Adjusted R Squared values of .946 and .922 respectively. The R Squared value determines the percent of explanation of the dependent variable, number of days to 100% mold growth in this study, which is dependent on the factors within this study. So, about 92% of the mold growth can be attributed to the moisture on the materials. The other 8% is due to other factors not tested or directly monitored in this study.

Table 6. ANOVA table--values of significance.

Tests of Between-Subjects Effects

Dependent Variable: moldcoverage

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	14831.333[a]	7	2118.762	40.071	.000
Intercept	18592.667	1	18592.667	351.634	.000
Moisture	80.667	1	80.667	1.526	.235
Material	14562.000	3	4854.000	91.801	.000
Moisture * Material	188.667	3	62.889	1.189	.345
Error	846.000	16	52.875		
Total	34270.000	24			
Corrected Total	15677.333	23			

a. R Squared = .946 (Adjusted R Squared = .922)

To further compare the different materials to each other, the Bonferoni Pairwise comparisons test, Table 7 was used. This test compares the means of each material to the other three materials. Cotton, material number 4, is significantly different from all of the other materials. Cork, material number 2, is not significantly different from either wool, material number 1, or straw, material number 3. However, straw and wool act significantly different from each other. Despite showing statistical significance in the difference in the rate of mold growth between some of the materials, all of the materials were highly susceptible to mold growth in the presence of moisture.

Table 7. Bonferroni pairwise comparisons between materials.

Pairwise Comparisons

Dependent Variable: moldcoverage

(I) Material	(J) Material	Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
1.00	2.00	-9.333	4.198	.246	-21.963	3.296
	3.00	-13.333*	4.198	.035	-25.963	-.704
	4.00	-63.333*	4.198	.000	-75.963	-50.704
2.00	1.00	9.333	4.198	.246	-3.296	21.963
	3.00	-4.000	4.198	1.000	-16.630	8.630
	4.00	-54.000*	4.198	.000	-66.630	-41.370
3.00	1.00	13.333*	4.198	.035	.704	25.963
	2.00	4.000	4.198	1.000	-8.630	16.630
	4.00	-50.000*	4.198	.000	-62.630	-37.370
4.00	1.00	63.333*	4.198	.000	50.704	75.963
	2.00	54.000*	4.198	.000	41.370	66.630
	3.00	50.000*	4.198	.000	37.370	62.630

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

a. Adjustment for multiple comparisons: Bonferroni.

Culturing and Identifying the Mold

Following the data collection, after all the samples had reached 100% visible coverage by mold, they were taken to a biology lab in order to have the mold types cultured and identified. Test samples were swabbed on an agar solution in Petri dishes. Figure 28 shows a collection of some the mycelium groups that grew from the test samples in the study.

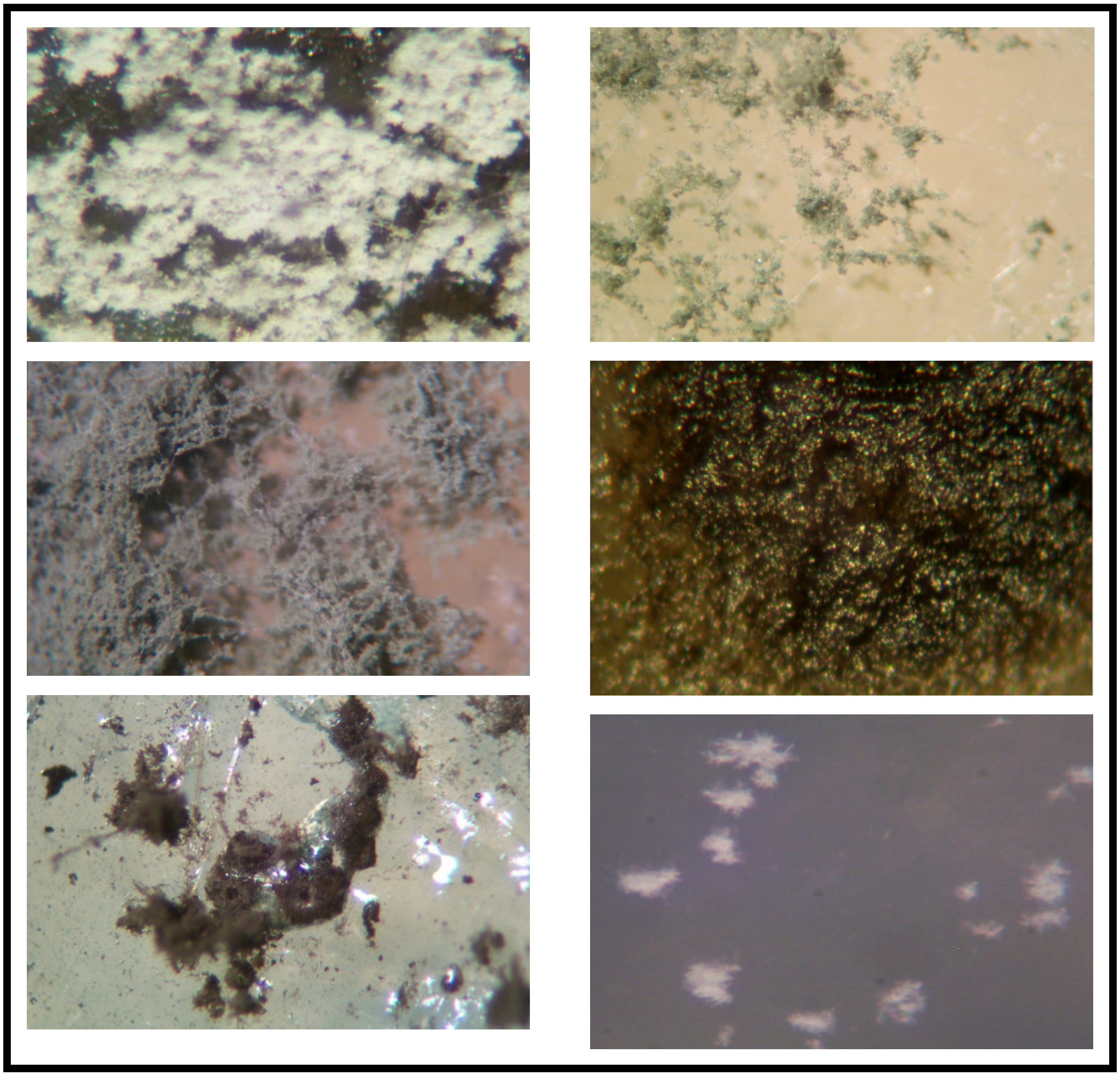

Figure 28. Mycelium--mold colonies from the samples—400 times magnification.

Figure 29 is a sample of pictures from the individual conidiophores that were isolated from the mycelium and that would cooperate for a photograph. From only four materials and 36 samples, more than five types of mold and numerous colonies of bacteria were identified. Once conidiophores were examined under the microscope, dichotomus identification keys, (see Appendix B to review), along with texts containing lengthy descriptions and biographies on the separate types of mold were used for identification. In addition to bacteria, *Aspergillius niger*, *Rhizopus*, *Gymnoascus*, *Arthrinium*, and another member of the *Aspergillius* family were isolated on the samples in the biology lab--see Appendix B for sample pictures from the identification keys.

An interesting find from typing the molds came from the mold growing on the pure white cotton. *Arthrinium*, is a mold that can be as white as snow and grows very quickly. This mold, while on the white cotton, would not initially show up due to its white color. Only after the mycelium started to produce dark black fruiting bodies or conidiophores, would the mold be distinguishable against its similar colored background. Therefore, the cotton most likely was not slower at growing mold after all.

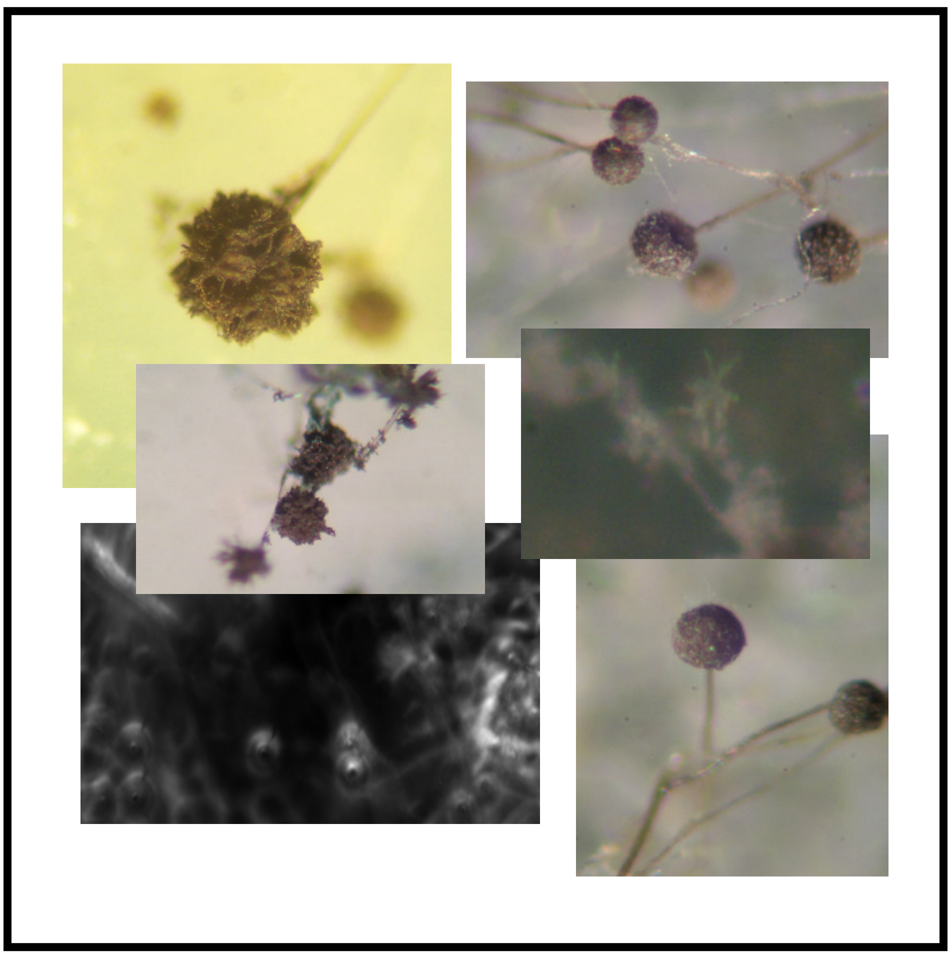

Figure 29. Individual condidiophores from samples—400 times magnification**.**

RESULTS

One of the original null hypotheses was that the amount of moisture, 0 mL, 25 mL, or 75 mL would not make a difference in mold growth, based on amount of coverage of a material. The alternative hypothesis was that the water amount would affect the amount of mold growth on a material. Based on the test results, there was an obvious difference in mold growth with the introduction of moisture, so the 0 mL of water results were removed from the data comparison, and only the 25 mL and 75 mL samples were compared. When the two amounts of water, 25 mL or low amount of moisture and 75 mL or high moisture were compared, there was no statistically significant difference in the rate of mold growth. As for materials, wool and cork, with straw lagging slightly behind, all grew mold extremely quickly. Cotton also grew mold very quickly, but took much longer to start mold growth and to spread. Interestingly, during the post study, it was determined that the mold growing on the cotton was exactly the same color as cotton, making only the fruiting bodies visible against the cotton, and camouflaging the main mycelium colonies.

CONCLUSIONS

Construction Trends

Cities and companies around the country and around the world are racing to be on the leading edge of the Green movement. LEED certified buildings are becoming the norm, and LEED certification guidelines for homes will be officially released soon, opening a huge market for natural rapidly renewable materials and recycled materials rich in nutrients for mold. These products work fine as building materials as long as they remain dry.

Moisture Infiltration

Due to flaws in design, construction, maintenance and use, or acts of God, moisture will eventually come in contact with most building materials at some point during a facility's life span. Figure 30 shows a picture of a bathroom. Due to a lack of maintenance, the missing tile and gaping hole in the 4th floor wall have become an avenue for moisture, mop water, and regular toilet leaks and overflow. For several years, water has freely entered this new outlet, sending the water into the cavity of the 4th floor exterior wall.

Figure 30. Hole in exterior wall in 4th floor restroom—open access to water.

Green Movement in Materials due to Mold

It is important to understand the materials being used in our homes and buildings. LEED guidelines are pushing for rapidly renewable and organic materials because they are easily replaced and their use has a low impact on the environment. However, once installed into a facility, an object of desired permanence, the cost of replacement becomes very high. Last, people spend, whether they are at home, work, school, and even leisure, a lot of time in doors. Air quality and indoor environmental health issues are very important. Molds create spores, allergens, and airborne toxins. Molds are also accompanied by large amounts of bacteria, which enjoy similar moist environments. Together mold and bacteria create an unhealthy and potentially even dangerous or deadly indoor environment. Buildings will never be designed, built, maintained, or utilized perfectly; and weather and natural disasters can not be predicted. The one thing we can have complete control over, the materials within the building, should be selected wisely. If building material trends are not changed, future generations may reflect back on the current environmental building movement and remember Green—not because it was eco-friendly, but due to the mold it produced.

RECOMMENDATIONS

Future Studies

Due to a limited amount of time and funding this study focused on four different types of rapidly renewable materials encapsulated in three differing amounts of moisture, zero moisture acting as a control group. Future research could look at additional types of rapidly renewable materials such as new growth certified lumber or straw board, wall building materials that include recycled materials such as dry wall or blown in recycled clothing and cotton mix, or combinations of rapidly renewable materials and recycled materials such as paper reinforced straw sandwich board—see Figure 31 of a sample.

Figure 31. Paper reinforced straw board, sold in 1.22 x 2.44m or 4' x 8' sheets.

Wall building materials were used in this study based on the concept of encapsulated moisture within a wall cavity. Future studies could examine other building products for areas such as flooring, ceiling or other potential wet areas. This study also tried to simulate field conditions; however, actual field tests could be implemented.

Rapidly renewable materials, if they didn't mold in the presence of moisture, could be good alternative building materials. Future studies could examine impregnating these materials with different substances such as boron in the form of borax or chlorine crystals in order to make them more resilient to mold, similar to how lumber can be treated with copper chromate to make it resilient to wood rot--a process also due to mold.

Another emerging field in construction science includes natural earthen materials. Earthen materials can be cut, molded, or compacted into exterior building components. Earthen fill can also be in combination with interlocking prefabricated structures or building component pieces. Earthen materials are known to contain numerous organic substances and can also harbor mold. Additional studies could examine potential effects and risks due to mold within the earthen materials.

Last, additional studies could be completed on the evolution of molds on materials. If materials are exposed to moisture or other living molds for long periods of time, more selective and rare molds may have an opportunity to grow. In light of this progression issue, studies need to be developed for accurate expedient testing and the remediation of molds.

Construction Managers

Construction managers need to carefully control the materials that are installed in a facility. Submittals and plans should be reviewed to ensure that if cellulose and carbohydrate based materials are installed, they should be carefully protected from moisture.

Next, since mold spores are everywhere, it is pertinent to keep all materials dry prior to installation to prevent mold growth. Moisture meters should be used to verify proper moisture content in lumber, paneling, trim, or any other material they may need to be acclimated to the area or installation to help prevent encapsulated construction moisture and cracks from developing.

Finally, construction managers should log all of their actions taken to ensure that the proper materials were used and they were installed in a dry condition. This will help protect construction companies from lawsuits connecting mold growth to contractor negligence.

Owners and Architects

Owners and architects have the biggest role in material selection. Since this is one of the few elements within construction that the owner and architect have complete control over, careful decision should be made when selecting materials that will be installed near areas the have a risk of being in contact with moisture.

Owners and architects should also require that sensitive materials be checked for moisture prior to installation. All parties should also work together to schedule materials and to provide sufficient laydown areas that are protected from moisture.

Finally, once the facility is in use, the building needs to be maintained properly to ensure environments of unwanted moisture and humidity do not occur. The owner is ultimately responsible to ensure that maintenance procedures are setup and followed.

Expected Benefits

This study and review of literature examines the potential hazards of using rapidly renewable materials created from cellulose or carbohydrates. Hopefully the results, which show that these materials are highly susceptible to mold, will act as an alarm. The current construction market is so caught up in the eco-friendly or environmental movements that the long-term effects of material use are being ignored. Mold has become a high liability issue for builders and facility owners. Areas impacted by Hurricane Katrina are now dealing with lasting health issues including Katrina Cough, as a result of mold. This study will hopefully bring about awareness to builders, owners, and most importantly the United States Green Building Council, of the dangers and long-term effects of using some rapidly renewable materials. The Green Building Council has started a very important and effective tool to help preserve resources for future generations. The Green Building Council has made changes and improvements to the LEED guidelines in the past. Hopefully, this study can bring about a critical examination of the entire material and resource section within the Green Building Guidelines—see Appendix A.

REFERENCES

Association of General Contractors of America. (2006). *Building Your Quality of Life*. Retrieved October 16, 2006, from http://www.agc.org/page.ww?section=Green+Construction&name=LEED+Green+Building+Rating+System#rate

Black, W. (2006). *A Practical Guide to Mold and the Indoor Environment in South Florida.* Fort Myers, FL: American Management Resources Corporation.

Bosselmann, K. (1995). *When Two Worlds Collide: Society and Ecology*, Wellington, New Zealand: The Print Centre.

Brown, L. (1988). *State of the World*, New York: Penguin Books Canada Ltd.

Canlen, B. (2002). Taking Up Residence. *Home Channel News.* Vol. 28, Iss. 14. p. 1-3 http://www.wbdg.org/release_010907.php Web page updated Jan 9, 2007

Chambers, N., Simmons, C., & Wackernagel, M. (2000). *Sharing Nature's Interest*, London: Earthscan Publications Ltd.

Christensen, C., (1965). *The Molds and Man*. Minneapolis, MN: Lund Press, Inc.

Chua, J., (2007). *Shroom to Grow: Home-Grown Insulation Gets Fungi*, Retrieved on 28 June 2007, from http://www.treehugger.com/files/2007/06/mushrooms_insulation.php

Cooke, R., & Whipps, J. (1993). *Ecophysiology of Fungi*. Cambridge, MA: Blackwell Scientific Publications, Inc.

Dion, M., & Rockman, A. (1996). *Concrete Jungle*, Saint Paul, MN: Juno Books.

Dix, N., & Webster, J. (1995). *Fungal Ecology*. London: Chapman & Hall.

Douglas, J., & Stirling, J. (1997). *Dampness in Buildings*. (Rev. ed.). London: Blackwell Science.

Finsand, M. (1989). *Fungi and Molds Teacher's Guide*, Nashua, NH: Delta Education Incorporated.

Gordan, J. (2007). *MSN City Guide*. Retrieved 28 June 2007 from http://cityguides.msn.com/citylife/greenarticle.aspx?cp-documentid=4848590

Green Maker Building Supply. (2007). *Renewable Materials*. Retrieved 14 June 2007 from http://www.greenmakersupply.com/pages/renewable_materials/51.php?PHPSESSID=48d29fe7c93f73e5af9957b8fda1fa74

Harland, E. (1999). *Eco-renovation*. White River Junction, VA: Chelsea Green Publishing Company.

Jennings, D. (1993). *Stress Tolerance of Fungi*. New York: Marcel Dekker, Inc.

Johnson, H. (1995). *Green Plans Greenprint for Sustainability*, Lincoln, NE: University of Nebraska Press.

Kavaler, L. (1964). *The Wonders of Fungi*. New York: The John Day Company.

Kibert, C. (2005). *Sustainable Construction*, Hoboken, NJ: John Wiley & Sons, Inc.

Leadership In Energy and Environmental Design. (2000). *Green Building Rating System for New Construction and Major Renovations.* Retrieved October 2, 2006, from http://www.usgbc.org/Docs/LEEDdocs/LEED_RS_v2-1.pdf

Lieff, M**.,** & Trechsel, H. (1982). *Moisture Migration in Buildings*. Philadelphia: ASTM.

Malloch, D. (1997). *Moulds: Isolation, Cultivation, Identification.* Retrieved April 15, 2007, from http://www.botany.utoronto.ca/ResearchLabs/MallochLab/Malloch_/Moulds/Contents.html

May, J. (2001). *My House is Killing Me*. Baltimore, MD: The Johns Hopkins University Press.

May, J., May, C. (2004). *The Mold Survival Guide for Your Home and for Your Health.* Baltimore, MD: The Johns Hopkins University Press.

Money, N. (2004). *Carpet Monsters and Killer Spores*. New York: Oxford University Press, Inc.

Moser, G., Pol, E., Bernard, Y., Bannes, M., Corraliza, J., Giuliani, M., (2003). *People Places and Sustainability*, Seattle, WA: Hogefe and Huber Publishers.

Oliver, R., Schweizer, M. (1999). *Molecular Fungal Biology*. Cambridge, UK: University Press, Cambridge.

Owen, D. R. (2006). Mold: Inspection, problems, and solutions. In C. Y. Rilovick, S. W. Hayes, & C. T. Carper (Eds.), *Environmental Training Symposium 2006* (pp. 686-690). Langley Air Force Base, VA: United States Air Force Headquarter Air Combat Command.

Pascoe, Elaine. (1999). *Slime Molds and Fungi.* Woodbridge, CT: Blackbirch Press Inc.

Pimlott, D. (2007). US Environmental-Friendly Building Booms. *Financial Times* Tuesday May 8 2007

Progovitz, R. (2003). *Black Mold: Your Health and Your Home*. Cleveland, NY: Forager Press, LLC.

Pugliese, M. (2006). *The Homeowner's Guide to Mold*. Kingston, MA: Construction Publishers & Consultants.

Robinson, J. (1996). *Life in 2030: Exploring a Sustainable Future for Canada*, Vancouver, British Columbia Canada: UBC Press.

Rosen, Gary. (2006a). *Locating Hidden Toxic Mold*. Tampa, FL: Hope Academic Press.

Rosen, Gary. (2006b). *Mold & Mold Toxin Remediation*. Tampa, FL: Hope Academic Press.

Rosen, Gary. (2006c). *Mold Assesment & Remediation Workshop*. Tampa, FL: Hope Academic Press.

Szabo, Liz. (2006). '*Katrina Cough' Sending Many To The Doctor*. Retrieved from the *USA Today* website, Health and Behavior section. Retrieved June 22, 2007, from http://www.usatoday.com/news/health/2006-08-27-katrina-cough_x.htm.

Schwartz, T. (1992). *Water in Exterior Building Walls*. Philadelphia: ASTM.

Steger, U. (2004). *The Business of Sustainability*, London: Antony Rowe Ltd.

U.S. Department of Labor Occupational Safety and Health (2007). *A Brief Guide to Mold in the Workplace: Safety and Health Information Bulletin.* Retrieved March 12, 2007, from http://www.osha.gov/dts/shib/shib101003.html

U.S. Environmental Protection Agency (2006). *Mold Remediation in Schools and Buildings.* Retrieved March 12, 2007from U.S. Environmental Protection Agency's Web Site: http://www.epa.gov/iaq/molds/mold_remediation.html

U.S. Green Building Council. (2006). *Green Building Links*, 2006. Retrieved from the U.S. Green Building Council Web site, http://www.usgbc.org/DisplayPage.aspx?CMSPageID=76#12

Wilson, A. (2006). *Building Materials: What Makes a Product Green?* Retrieved October 19, 2006, from BuildingGreen.com's Web site: http://www.buildinggreen.com/auth/article.cfm?fileName=090101a

Wikipedia, Online Encyclopedia. (2007a). *Fresh Kills Landfill*. Retrieved June 13, 2007, from http://en.wikipedia.org/wiki/Fresh_Kills_Landfill

Wikipedia, Online Encyclopedia. (2007b). *Definition of Heterotroph*. Retrieved January 8, 2007, from http://en.wikipedia.org/wiki/Heterotrophic

Wikipedia, Online Encyclopedia. (2007c). *Definition of Eukaryotic*. Retrieved January 8, 2007, from http://en.wikipedia.org/wiki/Eukaryotic.

Worrall, J. (1999). *Structure and Dynamics of Fungal Populations*. AH Dordrecht, Netherlands: Kluwer Academic Publishers.

APPENDIX A

LEED CATEGORY BREAKDOWN

Table 8. Sustainable site, water, and energy points. (Kibert, 2005).

LEED Categories and Credits		
	Sustainable Sites 14 Possible Points	
Prerequisite 1	Soil and Erosion Control	Required
Credit 1	Site Selection	1
Credit 2	Urban Redevelopment	1
Credit 3	Brownfields Redevelopment	1
Credit 4.1	Alternative Transportation (Public Transportation Access)	1
Credit 4.2	Alternative Transportation (Bicycle Storage and Changing Rooms)	1
Credit 4.3	Altertemative Transportation (Alternative Refueling Stations)	1
Credit 4.4	Alternative Transportation (Parking Capacity)	1
Credit 5.1	Reduced Site Disturbance (Protect or Restore Open Space)	1
Credit 5.2	Reduced Site Disturbance (Development Footprint)	1
Credit 6.1	Stormwater Management (Rate of Quantity)	1
Credit 6.2	Stormwater Management (Treatment)	1
Credit 7.1	Landscape and Exterior Design to Reduce Heat Islands (Nonroof)	1
Credit 7.2	Landscape and Exterior Design to Reduce Heat Islands (Roof)	1
Credit 8	Light Pollution	1
Water Efficiency 5 Possible Points		
Credit 1.1	Water-Efficient Landscaping (Reduce by 50%)	1
Credit 1.2	Water-Efficient Landscaping (No Potable Water Use On Irrigation)	1
Credit 2	Innovative Wastewater Technology	1
Credit 3.1	Water Use Reduction (20% Reduction)	1
Credit 3.2	Water Use Reduction (30% Reduction)	1
Energy and Atmosphere 17 Possible Points		
Prerequisite 1	Fundamental Building Systems Commissioning	Required
Prerequisite 2	Minimum Energy Performance	Required
Prerequisite 3	CFC Reduction in HVAC Equipment	Required
Credit 1.1	Optimize Energy Performance (20% new/10% existing)	1
Credit 1.2	Optimize Energy Performance (30% new/20% existing)	1
Credit 1.3	Optimize Energy Performance (40% new/30% existing)	1
Credit 1.4	Optimize Energy Performance (50% new/40% existing)	1
Credit 1.5	Optimize Energy Performance (60% new/50% existing)	1
Credit 2.1	Renewable Energy (5%)	1
Credit 2.2	Renewable Energy (10%)	1
Credit 2.3	Renewable Energy (20%)	1
Credit 3	Additional Commissioning	1
Credit 4	Ozone Depletion	1
Credit 5	Measurement and Verification	1
Credit 6	Green Power	1

Table 9. Resources, indoor environment, and design points. (Kibert, 2005).

LEED Categories and Credits		
Materials and Resources 13 Possible Points		
Prerequisite 1	Storage and Collection of Recyclables	Required
Credit 1.1	Building Reuse (Maintain 75% of Existing Shell	1
Credit 1.2	Building Reuse (Maintain 100% of Existing Shell	1
Credit 1.3	Building Reuse (Maintain 100% of Shell and 50% Nonshell	1
Credit 2.1	Construction Waste Management (Divert 50%)	1
Credit 2.2	Construction Waste Management (Divert 75%)	1
Credit 3.1	Resource Reuse (Specify 5%)	1
Credit 3.2	Resource Reuse (Specify 10%)	1
Credit 4.1	Recycled Content (Specify 25%)	1
Credit 4.2	Recycled Content (Specify 50%)	1
Credit 5.1	Local/Regional material (20% manufactured locally)	1
Credit 5.2	Local/Regional Materials (of 20% above, 50% harvested locally)	1
Credit 6	Rapidly Renewable Materials	1
Credit 7	Certified Wood	1
Indoor Environmental Quality 15 Possible Points		
Prerequisite 1	Minimum IAQ Performance	Required
Prerequisite 2	Environmental Tobacco Smoke (ETS) Control	Required
Credit 1	Carbon Dioxide (CO2) Monitoring	1
Credit 2	Increase Ventilation Effectiveness	1
Credit 3.1	Construction IAQ Management Plan (During Construction)	1
Credit 3.2	Construction IAQ Management Plan (Before Construction)	1
Credit 4.1	Low-Emitting Material (Adhesives)	1
Credit 4.2	Low-Emitting Materials (Paints)	1
Credit 4.3	Low-Emitting Materials (Carpet)	1
Credit 4.4	Low-Emitting Materials	1
Credit 5	Indoor Chemical Pollutant Control	1
Credit 6.1	Controllability of Systems (Perimeter)	1
Credit 6.2	Controllability of Stystems (Nonperimeter)	1
Credit 7.1	Thermal Comfort (Comply with ASHRAE 55-1992)	1
Credit 7.2	Thermal Comfort (Permanent Monitoring System)	1
Credit 8.1	Daylight and Views (Daylight 75% or Spaces)	1
Credit 8.2	Daylight and Views (Daylight 90% of Spaces)	1
Innovation and Design Process 5 Possible Points		
Credit 1.1	Innovation in Design	1
Credit 1.2	Innovation in Design	1
Credit 1.3	Innovation in Design	1
Credit 1.4	Innovation in Design	1
Credit 2	LEED Accredited Professional	1

APPENDIX B

DICHOTOMUS MOLD IDENTIFICATION KEYS

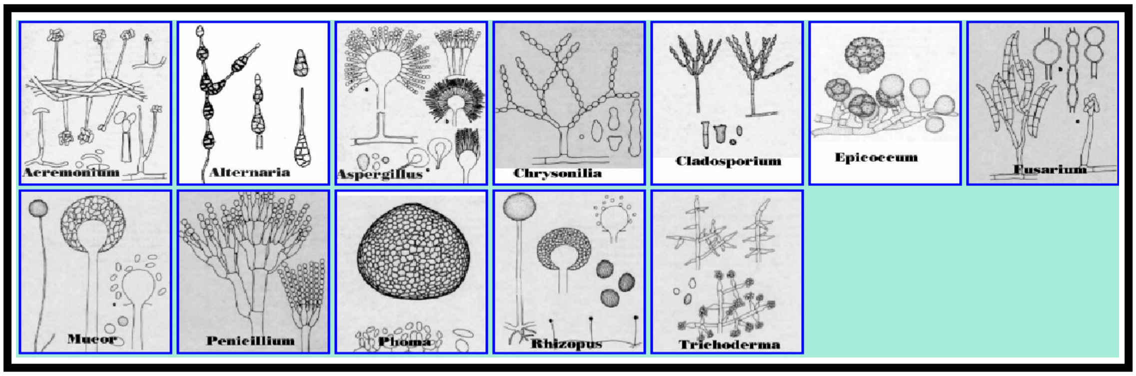

Figure 32. Group one common mold identification key (Malloch, 1997).

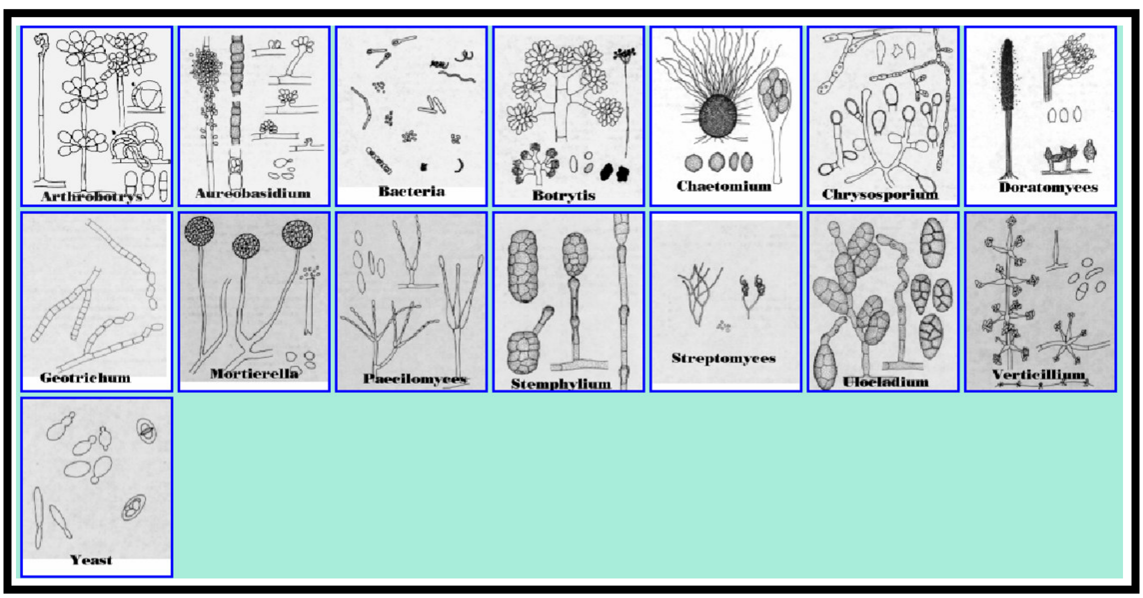

Figure 33. Group two common mold identification key (Malloch, 1997).

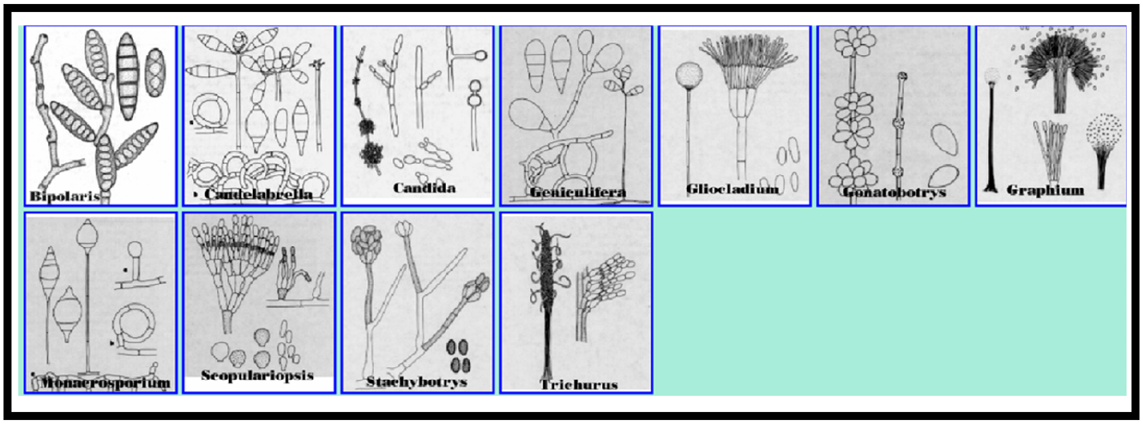

Figure 34. Group three common mold identification key (Malloch, 1997).

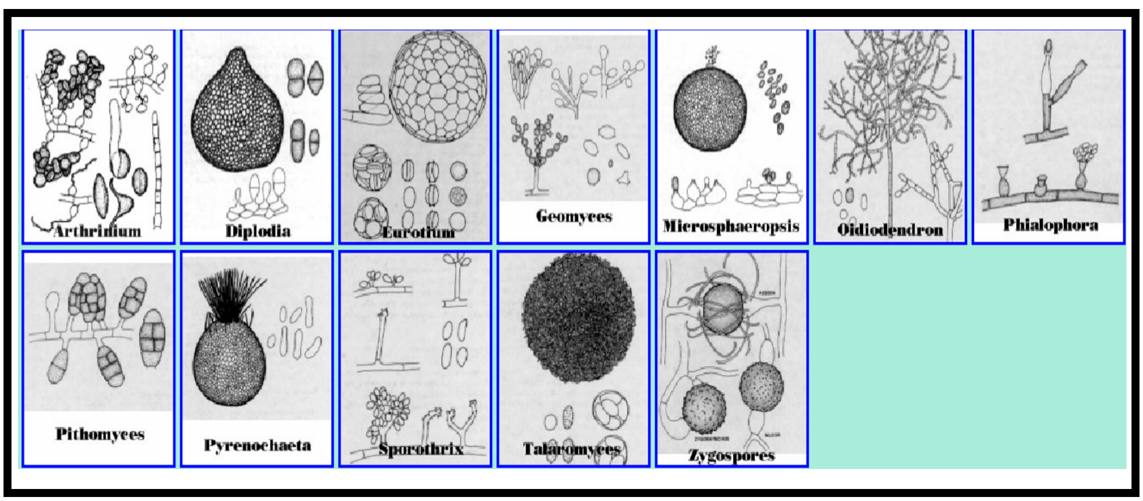

Figure 35. Group four common mold identification key (Malloch, 1997).

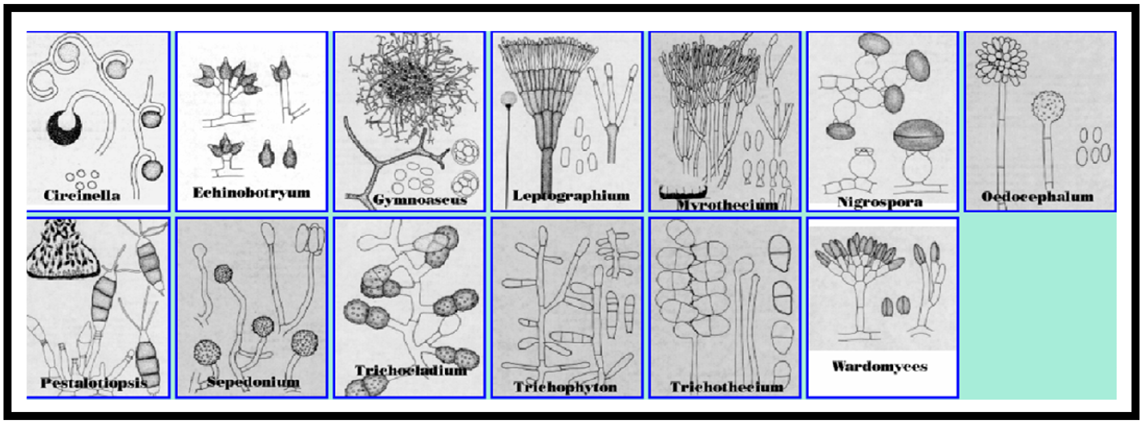

Figure 36. Group five common mold identification key (Malloch, 1997).

VITA

Education and Background

Aaron McGill Cooper received his Bachelor of Science degree in construction management with minors in business management and aerospace studies from Brigham Young University in April 2002. Upon graduation, Aaron Cooper was commissioned as a Second Lieutenant in the United States Air Force. Following assignments included Section Commander at Hill AFB UT, two base level construction management/field engineer assignments at Beale AFB CA, and a tour as the Engineering Flight Chief at Talil AB Iraq, Captain Cooper was accepted into graduate school at Texas A&M University through the Air Force's selective Civilian Institute Program. In September 2006, Captain Cooper started in the Master of Science Construction Management Program in the College of Architecture. His research interests include mold in construction practices and materials, and he plans to publish a book focusing on mold and the new direction of the building industry due to the "green" construction movement.

Contact Information

Upon graduating with a Master of Science in construction management, and certificates in Facility Management, and Graduate Teaching, Captain Cooper started a teaching assignment at the Air Force Institute of Technology at Wright Patterson AFB OH. Capt. Aaron Cooper may be contacted at 10155 Flat Woods Road, Caledonia MO, 63631. His email address is twominicoopers@yahoo.com.