The Effect of Carpet Fiber on the Growth of
***Dermatophagiodes farinae* in a Controlled Environment**

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Thesis submitted to the Faculty of the
Virginia Polytechnic Institute and State University
in partial fulfillment of the requirements for the degree of

Master of Science
in
Near Environments

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December 11, 2000
Blacksburg, Virginia

Keywords: House dust mites, Mites, Carpet, Carpet fibers, Allergy, Asthma

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(ABSTRACT)

Mites are endemic and allergy to mite excreta and parts is one of the most common allergies. Health care practitioners have recommended the removal of carpets from homes of people with mite allergies. Little, if any, consideration is given to the fact that some persons may benefit directly from the presence of carpet in their homes. In the allergen and mite research literature, carpets are rarely described as having unique characteristics and are generally referred to as a generic entity. Carpets, however, do have unique characteristics that define their construction, appearance, wearability, and cleanability.

Seventy-two pieces of commercially available, residential flooring materials were inoculated with identical numbers of mites, *Dermatophagiodes farinae*, and placed in the Textiles Conditioning Lab at Virginia Tech. The mites and carpet pieces were maintained in the lab, under identical, environmentally controlled conditions for 6 weeks, then the mites were extracted and counted.

On the basis of the results of statistical tests run on the study data, the null hypothesis, that there is no difference between the numbers of mites grown on the different flooring conditions, was rejected. Statistically significant differences exist between the hard floor and the nylon carpet, between hard floor and olefin carpets, but no difference between hard floor and wool carpet. Nylon was the carpet fiber that was most supportive of the growth of house dust mites, olefin was the second most supportive, and wool carpet and hard floor were similar in being the least supportive.

DEDICATION

This work is dedicated to my loving husband, Doctor Abe Andes. His consistency and dedication to our mutually agreed upon purpose provided a sustaining force through difficult times. For more than thirty years he has been my role model for an academician, researcher, and truly noble person.

And to our two daughters, Cecily and Melanie, I want to extend love and thanks for their willingness to tolerate unusual conditions in the home and to help me in reaching my goals.

ACKNOWLEDGEMENTS

This author wishes to acknowledge the assistance of her wonderful research committee. Dr. Kathleen Parrott provided professional knowledge and expertise, support and encouragement throughout the process and has been an example of how a professional educator can impact a student's life in a positive way. Her help extended far beyond that which one could reasonably expect from a research advisor. Dr. Judith Mollet made the actual research possible through her extensive knowledge of arthropod research and her willingness to help. Dr. Chen-Yu's knowledge of textile science and research added greatly to the quality of this research.

Dr. Susan Hutchinson made the incomprehensible world of statistics much less mysterious.

Appreciation is given to Carey Mitchell of Shaw Industries who provided valuable information and contributed the carpet samples used in the research study. Thanks to Dr Alan Leudtke of DuPont Nylon Flooring Systems for sharing information and helping to put me in contact with carpet industry experts.

Gratitude is also extended to Dr. Maureen Grasso and Dr. Sandra Rawls for their assistance is some initial work on this research.

And last, but not least, to my pal and fellow graduate student, April Allen, whose chipper attitude has served us well since The Dark Times and through our move to Virginia Tech.

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CHAPTER 1

INTRODUCTION

Carpet fibers differ in their ability to absorb moisture. The single greatest determinant of whether mites can exist in an environment is the relative humidity of that The quality of indoor air has concerned people throughout history. A perceived energy crisis in the 1970s focused attention on energy conservation in the United States. People were advised to insulate and make their homes "tighter" in order to conserve energy. One of the results of reducing the introduction of outside air into, and preventing the escape of conditioned or heated air out of homes and commercial buildings, was a reduction in the ventilation in buildings and a reduction in the quality of the indoor air.

An inadequately designed, "tightly" built home may suffer from deficient ventilation and increased moisture problems on the interior. Homes with increased relative humidity suffer from a plethora of problems, not the least of which is the provision of an environment in which an abundance of organisms can thrive. The presence of large numbers of organisms, and the debris from those organisms, in the indoor air is often the source of disease in human beings through infectious and Immunological mechanisms, or less frequently, by direct toxicity (Samet, 1990). One of the organisms dependent on a humid environment for its' survival is the dust mite.

Allergy and asthma are closely associated conditions. There is a dramatic increase in the incidence, mortality, and morbidity associated with asthma (Mannino et al., 1998). One of the most common allergens worldwide is the excreta of dust mites (Thien, Leung, Czarny, & Walters, 1994).

Carpet, in various forms, has been a part of interiors for hundreds of years. There are numerous advantages to having carpets in our homes and commercial spaces, including their aesthetic appeal, comfort, economy, temperature, and sound insulation abilities as well as safety considerations. However, in humid regions of the United States almost 100% of carpets contain dust mites (Arlian, 1989). While there is some debate over which interior environment provides the main foci of mite infestation in homes, it has become generally accepted that carpets are not the site with the greatest numbers of mites (Colloff, 1998).

One of the most common recommendations made to persons with allergies and asthma is allergen avoidance. In an attempt to help persons with mite allergies avoid contact with mite allergens, health care practitioners frequently recommend the removal of carpets. This recommendation is made despite the fact that very little research has been done in the area of carpet characteristics that influence the number of mites in different types of carpet. Indeed, carpet is usually mentioned with descriptives such as "wall to wall" or "fitted", with no mention of age or condition of the carpet, fiber content, or construction characteristics. Additionally, since 70% of the floors in the United States are covered with carpet (Davidsen, 1995) this is likely to be a recommendation that will be frequently ignored.

Problem Statement

Health care practitioners have recommended the removal of carpets from homes of people with mite allergies on the basis of little research regarding the interaction of mites and the varying carpet microenvironments. Additionally, little, if any, consideration is given to the fact that some persons may benefit directly from the presence of carpet in their homes. The comfort provided by the additional padding on the floor decreases fatigue and increases comfort (Rys & Konz, 1994). For another illustration of the value of carpeted floors, studies were done in which older patients who fell on carpeted floors were less likely to be injured than those who fell on vinyl floors (Healey, 1994) and other older patients walked more efficiently on carpeted floors than on vinyl floors (Willmott, 1986). In addition, carpets can be aesthetically pleasing and people have adorned their homes with carpet for centuries (Floor Covering, 1999). If carpets with particular construction characteristics less supportive of mite growth were identified, it would be possible to have the advantages of carpet without the disadvantages to persons with allergies.

Purpose of the Study

Research exists describing the effect on human beings of having mites in household carpet, the numbers of mites in carpets, conditions in the larger environment that allow mites to exist in interiors, the difficulty of killing or removing mites and their allergens from carpets, as well as comparisons of numbers of mites in carpeted and non-carpeted floors. Carpets are rarely described as having unique characteristics and are generally referred to as a generic entity. The characteristics of carpets that might effect the growth of mites within the carpet microenvironment have not been addressed. Carpets, however, do have unique characteristics that define their construction, appearance, wearability, and cleanability. Could those same characteristics that determine the appearance, wearability, and cleanability also determine that one carpet would be a more hospitable environment for mites than another?

environment. Would it be reasonable to assume that carpets constructed of fibers that retain more moisture provide a more supportive environment for the existence of mites?

The purpose of this study is to determine if, under identical, controlled environmental conditions, mites will exist in equal numbers in similarly constructed carpets designed with different fibers. The null hypothesis is, therefore:

$$H_O : C_W = C_N = C_P$$

where C_W is wool carpet, C_N is nylon carpet, and C_P is carpet constructed with polypropylene (olefin) fibers. And the alternate hypothesis is:

$$H_1 : C_W \neq C_N \neq C_P$$

Justification and Significance

Worldwide, the incidence and severity of allergy and asthma has been increasing (Mitka, 1999; Platts-Mills & de Weck, 1989). The fecal pellets of the house-dust mite, or mites, are the single most common allergen and house-dust mites are endemic. The usual recommendation made by healthcare professionals is that persons with allergies remove carpets from their homes because carpets trap allergens, those associated with house-dust mites, in particular. This recommendation is made on the basis of a great deal of research, very little, if any, of which has centered on the abilities of carpets with different construction characteristics to support the existence of house-dust mites.

This study is important because it will begin the systematic study of the effect of different carpet characteristics on the numbers of mites that will grow in the various carpet microenvironments. This study will investigate the effect of carpet fibers on the numbers of mites in various carpet samples. The fibers studied will be wool, the most absorbent fiber; polypropylene, the least absorbent fiber; and nylon, the most frequently used carpet fiber.

Overview of the Study

Carpet pieces that vary in their fiber content were inoculated with identical numbers of mites, *Dermatophagiodes farinae*, from an established colony and were then placed in the Textiles Conditioning Lab at Virginia Tech. The mites and carpet pieces were maintained in the lab, under identical, environmentally controlled conditions for six weeks. At the end of the study period, live mites were evacuated from the carpet pieces and counted. Means of the numbers of mites in the three fiber type categories were then compared statistically to determine if the type of fiber had an effect on the numbers of mites growing in the different carpet pieces.

Assumptions

1. Carpets used in this study are representative of residential carpets available to consumers today.
2. Since study carpets were delivered directly from the manufacturer and were sealed at the time of delivery, it is assumed that the samples were not infested with mites prior to the controlled introduction of mites during the study.

Limitations

1. It was not possible to control carpet construction variables other than the carpet fiber for this study. Because of this fact, the effects of other carpet construction variables, while present, were not considered in the research design.
2. Because the research is very preliminary, it is inappropriate to make other than cursory judgements based on these findings.

Definition of Terms

<u>Carpet</u> – a soft, textile floor covering; generally, a securely fastened or anchored floor covering is referred to as a carpet

Rug – a soft, textile floor covering; usually, a smaller, loosely laid floor covering is called a rug

Face fiber – also called the pile fiber, the fiber that appears on the top, or pile surface, of a carpet. The fiber composition of face fibers and the fibers used in backing structures is often markedly different.

Tackless strip – a narrow strip of wood imbedded with rows of short nails that is installed with the pointed sides of the nails up and used to secure the ends of wall-to-wall carpet.

Moisture regain – the ability of fibers to absorb vapor-phase moisture; a comparison of different fibers ability to absorb moisture is based on moisture regain values.

Substrate - the layer or material lying underneath a material, in this case the carpet or carpet pad

CHAPTER 2

BACKGROUND: CARPET

History of Carpet

Carpet is a common floor covering in today's homes and offices. The first carpets characterized by pile surfaces were probably cured animal skins laid on the dwelling floors of early hunters. Those floor coverings served many of the functions that floor coverings serve today – protection from hard and cold floors, providing a pleasing tactile surface, and decoration (Floor Covering, 1999). In the Middle East during the 4th or 5th millennium BC, floor coverings were plaited rushes (Rug and Carpet, 1999) and in ancient Egypt, they were woven grasses used to cover bare dirt floors (Hall, 1993).

During the 4th millennium BC, Egyptians began to weave linen carpet with woolen cloth ornamentation. This development spread through the Middle East, Mongolia, and China and was the origin of what we know today as Oriental rugs. Earliest Chinese rugs were made with cotton or wool backing and silk pile; silk gradually being replaced by wool. Nomads in Central Asia wove their woolen rugs on simple horizontal looms that could be rolled up for travel (Floor Covering, 1999).

Italian merchants imported Oriental rugs to Europe during the Middle Ages. The rugs hung on the walls while Europeans walked on woven rush and straw floor coverings. When the Moors settled in Spain, they brought carpets and weavers; weaving began as a trade and spread throughout Europe. By 1600, French weavers had formed a guild and in the early 1700's, the English followed suit and chartered carpet weavers in Wilton and Axminster (Floor Covering, 1999).

During the 18th Century, machinery was developed that radically improved textile manufacturing, and along with the steam engine, led to the invention of the power loom. The Jacquard loom system for controlling the warp yarns began to replace the complicated system of harnesses used in hand looms (Floor Covering, 1999).

Native Americans did not use hand-knotted rug making techniques and made flat-woven floor covering from the time of their earliest known history. Early American colonist made rugs using a variety of techniques including knitting, crocheting, braiding embroidering, and hooking (Rug and Carpet, 1999). Because the use of carpets had become popular in the eastern United States by the early 1800s, factories were built in New England, New York, and Pennsylvania and the first power loom appeared in 1841 (Floor Covering, 1999).

Prior to the 19th Century, the term "carpet" referred to any cover, such as a wall hanging or a table covering (Rug and Carpet, 1999), and was generally considered too valuable to walk on. Instead, woven carpets imported from the East would have been placed under furniture in European homes and featured in portraits of their owners (Calloway & Cromley, 1996). In 1876, the development of an Axminster loom stimulated the British and European carpet industry by permitting use of a wide range of colors and design (Floor Covering, 1999). Loom width increased, providing larger unseamed carpets and economy of production. The introduction of synthetic yarn and needle tufting through a prewoven backing as a manufacturing process was developed after World War II and is responsible for the majority of carpet production in the United States today (The Carpet and Rug Institute, 1995).

Uses of Carpet

Beauty

The beauty of carpet has long been appreciated by many cultures. Before the invention of the power loom, the luxury of owning beautiful carpets was available only to the most wealthy Europeans and Americans. Those who owned carpets displayed them prominently on their walls. Carpets were too precious to allow people to walk on them (Calloway & Cromley, 1996). The trend continues, and when surveyed by the American Association of Textile Chemist and Colorists, American women reported that they enjoyed the pretty or elegant appearance of the carpets in their homes (Powers, 1984).

Comfort

Rys and Konz (1994) summarized their previous work on fatigue during prolonged standing on different floor surfaces. They reported that mats were consistently preferred over concrete flooring and that comfort was inversely related to compression from the weight of the body. American women reported that one of the things they enjoyed the most about the carpet in their homes was its thick pile and soft feeling (Powers, 1984).

Economy

Carpet is an economical choice of floor covering material. The editors of *Contract Design* note the transformation of carpet from the epitome of luxury and privilege to an affordable product that constitutes a majority of flooring produced ("Watch Your Feet," 1996). Seventy percent of the floors in the United States are covered with carpet (Davidsen, 1995).

In the 45-year period between 1950 and 1995, the cost of carpet increased by only 82.1%. During that same period, the combined cost of all commodities increased by 356.8% (The Carpet and Rug Institute, 1996).

Safety

Carpet provides a safe walking surface because it is not slippery. However, “throw rugs” can present a tripping hazard and should be removed from the homes of the elderly as a precaution against falling (Hazzard, Andres, Bierman, & Blass, 1990).

Willmott (1986) measured gait speed and step length in 58 elderly hospital patients on a carpeted floor and a shiny vinyl floor. He concluded that, “for the group as a whole, the mean gait speed and step length were significantly greater on carpet than on vinyl, i.e. walking was more efficient on carpet “ (p.119). Further, some of the patients reported being fearful of walking on the shiny vinyl floor, but none reported difficulty in walking on carpet.

Since carpet provides a surface that is softer than many other flooring materials, such as wood, concrete, and tile, it is possible that it also provides a safer surface in the event of a fall. The King County Medical Examiner’s Office in Seattle released a study analyzing 75 cases of fatal ground-level falls over a 48-month period (Hartshorne, Haruff, & Alvord, 1996). The researchers reported that their experience supports frequent findings in the medical literature that older persons are more vulnerable to injury from minor falls, more likely to incur a head injury as a result of a fall, and more likely to have a poor outcome from their injury. The authors note that studies of elderly patients found that most falls occurred in the home and 20% were ground-level falls. They concluded that any padding between the head and impact surface would greatly reduce the risk of serious injury and recommended altering the environment of elders by installing impact absorbing surfaces. Carpet would seem to be an appropriate material to use for this purpose.

Cannava (1994), an interior designer with "gerodesign" experience, recommends using a tight-woven carpet with a smooth surface when designing living spaces for the elderly. The resilient surface provides a surface described as "friendly" to musculoskeletal movement and wheelchair passage. Additionally, the presence of carpet decreases the risk of injury from falling and breakage of items that are accidentally dropped on the carpet (Cannava, 1994).

Sound and Thermal Insulation

Interior designers can limit general ambient noise generated within a space by making thoughtful decisions in materials selection. Wise materials selection can deal with noise problems at noise levels below factory machinery levels. Glass, metal, tile, and plaster surfaces not only reflect noise but can also generate excessive noise, such as the clatter of silver and dishes on unprotected table tops and chairs scraping on tile floors. Soft, sound-absorbing materials used on floors, walls, windows, tabletops, and ceilings reduce noise levels significantly. Residential spaces rarely need more sound absorbing materials than will normally be present in the form of carpet and upholstered furnishings (Pile, 1995).

Noise transmitted from one space to another is a more difficult problem. Noise is transmitted in a downward direction more readily than it is in an upward direction. An NRC (Noise Reduction Coefficient) value is a number indicating the ability of a material to absorb sound, and ranges from 0.0, which indicates no sound being absorbed, to 0.99, which would indicate almost all sound being absorbed. The NRC rating for carpet over pad can be up to 0.6, which indicates carpet is a valuable material for the prevention of sound transmission (Pile, 1995).

Hatch, et al., (1991) summarizes the role of carpet in improving acoustics by stating, "Carpets have excellent sound absorption ability; they are superior in this respect to other flooring materials. Depending on the frequency of the undesirable sound and the structure of the carpet, the sound absorption coefficient can be as high as .90" (p.20).

Carpet and carpet cushions have features that increase thermal resistance, thereby providing insulating properties (Yeager, 1988). First, textile fibers have low conductivity (high thermal resistance) and do not readily transmit heat energy along the length of fibers. Second, when fibers are spun into yarns or constructed into fabrics or systems, such as carpets, air is trapped in spaces between the fibers and yarns increasing the insulating properties. Third, the large volume of air trapped within a textile system provides additional insulation. And fourth, textile systems greatly reduce the radiation of heat from the surface of the fibers (Hatch, 1993). Textile fibers can also be engineered to have appearance characteristics that increase the reflectance of ambient light, thereby reducing the need for artificial illumination (Yeager, 1988).

Carpet Variables

Fibers

The Carpet and Rug Institute (1996) reports that in 1995 synthetic fibers were dominant in the face fiber market, with nylon comprising 62.3%, polypropylene (olefin) 31.5%, and polyester 5.8% of the market. While wool constitutes less than 1% of the face fiber market, it is still considered the premier carpet fiber (Hall, 1993).

Synthetic Fibers

Ninety-nine percent of the fibers used as face fibers for carpets are synthetic (The Carpet and Rug Institute, 1995). These fibers are created by a process called extrusion, in which a molten polymer is forced through tiny holes in a metal plate, called a spinnerette. Some synthetic fibers are colored, or solution-dyed, before they are extruded. In the next stage of production, the fibers are cooled and then drawn or stretched out, a process that aligns the molecules and strengthens the fiber, and may impart other physical characteristics to the fibers. Some fibers are then texturized, a process that increases the apparent volume of the fiber (Hollen, Saddler, Langford, & Kadolph, 1988).

By changing the shape of the spinnerette, the cross sectional shape of the extruded fibers can be altered. The shape of the fiber determines many properties of the fiber, such as luster, bulkiness, texture retention, and ability to hide soil (The Carpet and Rug Institute, 1995). Carpet fibers are larger than fibers used in the clothing industry since the larger diameter results in a fiber that is more resistant to crushing and bending (Hollen et al., 1988).

Carpet fiber characteristics may be altered to affect things such as carpet soiling, which may be real or apparent, both conditions being very fiber-dependent. Apparent soiling is a condition resulting from the color, shape, and optical characteristics of the fiber. The smooth, round shape of many synthetic fibers retains the least amount of soil. However, when this smooth round shape is combined with the transparent quality of nylon, the most commonly used fiber, the result is apparent soiling. Apparent soil makes existing soil seem worse than it really is because existing soil shows through the transparent fiber and the roundness of the fiber tends to magnify the appearance of the soil (Hollen et al., 1988).

One way that textile fibers are classified is determined by whether or not they facilitate the transmission of negatively charge electrons along their surface. Those fibers that do not transmit electrical charges easily cause electrical charges to build up and result in problems such as static cling in clothing and annoying static shocks when the charges accumulate and are suddenly transferred to an object that conducts electrical currents more readily. Static electricity in carpet fibers is a problem because it is annoying but also because the static charge causes the carpet to attract dirt. In addition to minor annoyances caused by static electricity, the electrical charges can cause explosions and fire when they occur in atmospheres containing volatile gasses, such as those in surgical suites (Hollen et al., 1988), or interfere with electronic equipment.

Carpets or fibers can be specifically engineered in order to prevent the buildup of static electricity, cause it to be continuously discharged, or discharged at a rate lower than human sensitivity. Fibers can be engineered by adding static reducing compounds to the polymer solution, enclosing a filament within a sheath of conductive material, or coating a filament with a highly conductive material such as carbon black. Carpets can have metal fibers placed within the carpet structure at regular intervals during construction, spun with staple or filament fibers, or intertwined with multifilament fibers in yarn (Yeager, 1988).

Allergic reactions to untreated synthetic fibers are rare. The main cause of allergic contact dermatitis in textiles is dyes and the instances of irritation or dermatitis from dyes are few (Stoors, 1986).

Nylon. In 1928, as a result of basic scientific research into how small molecules were joined to form large molecules, or polymers, Dr. Wallace Carothers of the Du Pont Company, discovered the first synthetic fiber, nylon (Hollen et al., 1988). Almost 80 years later, nylon comprises 65% of all the face fibers used in carpet (The Carpet and Rug Institute, 1995).

When viewed under a microscope, regular nylon resembles fine glass rods, being round in cross-section and uniform throughout the length of the fiber. Unless it has been delustered or solution-dyed, the fiber is transparent. In the production of nylon fibers for carpet use, the change in shape from round to trilobal or the addition of voids to a square shaped fiber are measures designed to reduce apparent soiling (Hollen et al., 1988).

When compared by weight, nylon is stronger than steel wire. This is one of the reasons it is the called the “strong fiber”. The other reasons are because of its tenacity, or ability to elongate and recover. Another valuable property is its abrasion resistance. Nylon is unsurpassed in its ability to withstand rubbing, flexing, and scraping without being worn away. Additionally, nylon has high compressional resilience which contributes directly to the ability of nylon carpet fibers to maintain loft and resist matting in high traffic areas (Hatch, 1993).

At a rate of up to 4.5%, nylon has the highest moisture regain of all the synthetic fibers. While this is a high rate for synthetic fibers, it is such a low rate of absorbency as to present a problem with the build-up of static electricity. This problem is addressed with the use of antistatic-type filaments and finishes, and by blending this fiber with other fibers that are low static (Hollen et al., 1988).

Soil is attracted to and held on the surface of the nylon fiber. Particles in the air are attracted to nylon because of its static nature. Nylon is readily stained, particularly with oil-borne stains. Nylon carpet can be cleaned effectively with dry powders or by an extraction method to remove dulling film and deeply embedded dirt (Hatch, 1993).

Polypropylene (Olefin). Production of polypropylene (olefin) began in the United States in 1960 with the carpet industry. Attempts had been made since he early 1920's to polymerize ethylene but were largely unsuccessful because the early filaments did not have enough strength or a high enough melting point. The low melting point of 325° remains a problem and compares unfavorably with other synthetic fibers (Hollen et al., 1988).

Although olefin is inexpensive to produce, it is strong and resistant to abrasion. Even though olefin has a rate of moisture regain of less than 1%, it is static resistant. This unique characteristic is due to the fact that polypropylene is a non-polar fiber and fibers are held together by chrystallinity alone. Non-polar fibers do not make electrons available to be brought to the surface of the fiber to be transferred along the length of the fiber and experienced as a static shock (Hatch, 1993; Hollen et al., 1988). Because these fibers are essentially non-absorbent, they are not affected by water-borne stains and dry quickly. These fibers also have excellent wicking abilities, which brings moisture away from the surface of the skin and makes fabrics constructed of olefin comfortable to wear. However, olefins are more prone to greasy or oily stains than nylon. These fibers are resistant to acids, alkalis, insects, and microorganisms. Some consumers object to what is described in the textile industry as a "waxy hand", or undesirable tactile quality of products made from olefin fibers (Hollen et al., 1988).

Polyester. Polyester was another fiber discovered by Dr. Carothers in his polymer research program at Du Pont. Polyester development was put aside when nylon research began and was developed into its fiber form in England. Microscopically, polyester resembles nylon greatly though the polyester fiber is not as transparent as the nylon fiber (Hollen et al., 1988).

Polyester is abrasion resistant and strong. Because of its low moisture regain, 0.4%, polyester dries quickly, but is more electrostatic than most other synthetic fibers. Low absorbency causes the fiber to resist water-soluble stains. Polyester is oleophilic, or oil absorbent and will retain an oily stain, and many who recall the "ring around the collar" commercials will associate this characteristic with cotton /polyester shirts. In apparel, when soil has accumulated on the fabric, bacteria will grow and result in an odor (Hollen et al., 1988).

Polyester accounts for only 7% of the carpet market and most of the carpet that is made of polyester is made for the residential market (The Carpet and Rug Institute, 1995). The reason polyester is not competitive in the carpet market is because of its low compression resilience (Hatch, 1993).

Wool

Wool is a natural protein fiber from the hair or fur of animals and is the most widely used protein fiber. The cortex comprises the major portion of the fiber. The cortex is made of long cylindrical shaped cells with slightly different chemical and physical properties on each side. This difference in properties causes the cells to react differently to moisture and temperature that results in a unique three-dimensional crimp in the wool fiber. As the fiber goes up and down in waves, it also turns on its axis. The unique shape of the fiber gives wool three of its characteristic qualities. The crimp helps the fibers to hold together as a yarn. The crimp and the twist of the fiber on its axis cause the fiber to act as a spring, which results in a very elastic fiber. These same qualities give yarn and fabrics made of wool a three dimensional quality known as loft (Hollen et al., 1988).

The outer layer of the fiber, known as the cuticle, is made of an epicuticle and a horny, non-fibrous layer of scales. The scales vary in different qualities of wool but can generally be described as resembling shingles on a roof or scales on a fish. The scales project from the fiber and the ends of the scale point towards the end of the fiber. The results of having scales on the fiber are skin irritation in some individuals, increased resistance to abrasion, and a property known as felting. When wool fibers are agitated in the presence of heat and moisture, the scales of the fiber interlock, preventing the fiber from returning to its original position in the fabric, resulting in shrinking and felting of the fabric. In the extreme, felting can result in a 50% reduction in the size of the fabric. The potential for felting makes cleaning wool difficult (Hollen et al., 1988).

The scales on each wool fiber are covered by a thin, non-protein membrane called the epicure. While this membrane provides water repellence to the fiber, it is easily damaged by mechanical action. Wool can have a moisture regain of 13-18% without surface wetting and atmospheric moisture is essential to maintain the flexibility of wool fibers. For example, wool carpets become brittle when the atmosphere moisture content is too low (Hollen et al., 1988).

The surface of the wool fiber is naturally waxy and water repellent and this characteristic allows many spills to be wiped up before a stain occurs or before oily soil is absorbed. The fiber is capable of absorbing large quantities of oily soil. Fortunately, soil is readily released from wool fibers in both solvent-based and water-based cleaning. It is possible to release soil from wool carpet by steam cleaning (Hatch, 1993).

Insects such as moths and carpet beetle larvae thrive on wool fibers. For this reason, the dying and finishing processes designed for wool generally are combined with mothproofing treatments. This process renders the wool fibers indigestible by insects by modifying a chemical linkage, thus becoming an integral part of the fiber. All domestic wool floor coverings are treated to be moth resistant (Yeager, 1988).

Pyrethrum is a natural insecticide found in the plant chrysanthemum and pyrethrins are a class of insecticides derived from this natural material. There are several synthetic forms of pyrethrum, called pyrethroids, one of which is permethrin. The effect of pyrethrins and pyrethroids on arthropods is paralysis and death by blocking excitation of the nervous system (Brooks, Gochfeld, Herzstein, Schrenker, & Jackson, 1995). In humans, “accidental ingestion of pyrethrin-containing insecticides rarely requires aggressive treatment. Inhalation exposures can be treated simply by having the victim leave the area and breathe fresh air” (Brooks, et al., 1995, p. 405). Permethrins are commonly used in homes in the form of insect sprays and foggers and agents to remove head lice (Brooks et al., 1995) and by the Forest Service of the United States Department of Agriculture for insect infestations (Forest Service, 1995). Most wool carpets are treated with permethrin (K. Sellers, personal communication, October 2, 2000).

The major use of wool in the home furnishings industry is in carpets and rugs, though wool comprises less than 1% of the fibers used to make carpet. Wool is often more expensive than synthetic fibers and is still perceived as the premier carpet fiber (The Carpet and Rug Institute, 1995).

Allergic dermatitis traceable to natural, untreated wool is rare, though irritation and inflammation of the skin placed in direct contact with wool fabrics is not unusual, particularly in persons with sensitized skin. The irritation caused by wool fibers can usually be avoided by placing a smooth and soft fabric between the sensitized skin and the wool fabric (Stoors, 1986).

Carpet Construction Variables

Yarn Construction

"A yarn is a continuous strand of textile fibers, filaments, or material in a form suitable for knitting, weaving, or otherwise intertwining to form a textile fabric" (Hollen et al., 1988, p. 152). A yarn can be spun of short fibers twisted together, or a filament yarn made of long fibers that are twisted or grouped together (Hollen et al., 1988).

Most yarn is twisted to increase its strength and to achieve the desired appearance. The choice of high or low twist, as well as short or long fibers affects the appearance, function and durability of textile products. For example, a yarn with more twists in the length, referred to as high twist, results in carpet which is described as frieze. Yarn that receives a medium amount of twist results in a saxony carpet, yarn with a low amount of twist results in a carpet described as velour or saxony plush (Hollen et al., 1988).

Construction Methods

The major carpet construction methods are tufting, weaving, knitting, needlepunching, and bonding (The Carpet and Rug Institute, 1995). Of the total square yards of carpet produced in the United States during 1995, 91.7% was tufted. When the share of market production is based on dollars annually, the share increases to 92.6% (The Carpet and Rug Institute, 1996).

Tufted Carpet. Tufting is a process that involves threaded needles punching through the back of a pre-made backing material resulting in loops of yarn on the front, or face, of the backing material. These loops can be left in place or cut to achieve a cut-pile. A predetermined combination of cut and uncut loops in a pattern is an alternative tufting process. If predyed yarn was not used, the unbacked carpet can be sent for dying or any variety of finishing processes before a latex backing is applied to securely bond the tufts in place. To provide greater dimensional stability, an adhesive and secondary backing material is frequently applied (The Carpet and Rug Institute, 1995).

Woven Carpet. During 1995, 1.7% of the square yards of carpet produced in the United States consisted of woven carpet (The Carpet and Rug Institute, 1996). Woven carpet is specified in commercial installations when a particularly tight construction and dense pile is required, or a particularly intricate pattern is designed. In the past, most woven carpet was made of wool but nylon, acrylics, and blends are more commonly used today (Reznikoff, 1979).

Woven carpets can be Axminster, Wiltons, or velvets, depending on the type and complexity of the loom used to weave the carpet. Velvet is produced on the least complex looms and is the most frequently produced woven carpet. The Jacquard loom produces Wilton carpet in a wide variety of patterns and textures. The most complex looms, of which there are probably only three or four in the United States, produce Axminster in an unlimited variety of colors and patterns (Reznikoff, 1979).

While the complexity and type of loom varies, the basic method is similar. Warp yarns, which form the back of the carpet, are stretched tightly from large beams that allow the yarns to slowly unwind as weaving progresses. The warp yarns alternately rise and recede to form a space between them called the shed, through which a shuttle carrying the filling yarn is shot. The face yarn of the carpet is a yarn that is looped over wires that are at right angles to the warp or weft yarn as it proceeds into the loom. The yarn loops are held in place by the filling yarns (The Carpet and Rug Institute, 1995).

Other Carpet Construction Methods. All other types of construction (knitted, needlepunch, braided, hooked, and others) comprised 6.7% of market production in the United States in 1995 (The Carpet and Rug Institute, 1996). Carpet is knitted in a complex process during which the stitching, backing, and pile yarns are looped together by three sets of needles. Knitted carpet is less stiff but similar to woven carpet. The quality of the carpet depends on the amount of yarn in the pile and the durability of the attachment of the face, chain, and backing yarns (The Carpet and Rug Institute, 1995).

To create a needlepunched carpet, often referred to as indoor – outdoor carpet, webs of fibers are superimposed on each other to create a thick, loose batting. As the batting passes through the needlepunching machine, the batting is repeatedly penetrated by barbed needles which causes the fibers to become entangled. The result is durable, felt-like fabric that is very permeable to liquids. This permeability is an asset when the structure is installed outdoors since it can be hosed off to remove debris but presents very significant problems when installed indoors (Yeager, 1988).

Implanting yarns, fiber bats, or webs into a vinyl or thermoplastic-coated backing creates bonded carpet. These carpets are often cut for modular carpet tiles (The Carpet and Rug Institute, 1995).

Carpet Backing

There is a greater variety of backing systems for commercial carpets than for residential carpets, since backing systems are designed to perform a specific function. Generally backing systems are composed of three elements: the primary backing, the applied chemical adhesive, and the secondary backing. The chemical adhesive, usually latex or vinyl, is applied to the primary backing to secure the yarns in place. A secondary backing (cushion) is added to provide additional pile-yarn stability and to impart additional dimensional stability to the carpet structure (The Carpet and Rug Institute, 1995).

In tufted carpet, the primary backing is almost always a prewoven film and polypropylene and polyester are the most commonly used fibers. In tufted carpet, the most frequently used secondary backing material is woven polypropylene, but polyester and jute fibers can also be used (The Carpet and Rug Institute, 1995).

When constructing woven and knitted carpet, the pile yarns and backing fabric are combined during the process of fabric formation. In woven carpets, the typical backing materials can be jute, cotton, polypropylene, polyester, viscose rayon, and blends or combinations of fibers, with polypropylene being the primary construction yarn (The Carpet and Rug Institute, 1995).

Needlepunched carpet typically does not use a primary or secondary backing. 0nce the fabric has been constructed and dyed, the carpet is finished using one of the following techniques: lamination of a secondary backing fabric, adhesion of a synthetic foam cushion, or coating with a synthetic latex, vinyl, or other polymer. Bonded carpet is typically backed with fiberglass matting (The Carpet and Rug Institute, 1995).

The choice of bonding and laminating material helps determine many of the physical properties of the carpet, such a tuft-bind, dimensional stability, minimum fuzzing and pilling, secondary backing adhesion, resistance of edge ravel, and durability. The most frequently used backcoating and laminating compound is styrene butadiene latex, but other compounds, such as polyvinyl chloride, amorphous resin, natural latex, ethylene vinyl acetate, polyethylene, and polyurethane can be used also (The Carpet and Rug Institute, 1995).

Finishes

"A finish is defined as anything that is done to fiber, yarn, or fabric before or after weaving or knitting to change the appearance (what is seen), the hand (what is felt), or the performance (what the fabric does)" (Hollen et al., 1988, p. 300). Finishing is usually done after the carpet has been constructed and colored. Residential carpets are commonly given a stain-resistant finish while commercial carpets receive a soil-retardant treatment, which helps the carpet resist stains. Carpet intended for hospital use is often given an anti-microbial finish to help reduce the propagation and spread of microorganisms (Hollen et al., 1988).

Types of Carpet Installation

Carpet Installation

Carpet is installed using one of two methods: stretch-in or glue-down.

In residences and in some commercial applications, when a cushion underlay is important, the stretch-in method is preferred. Using a power stretcher, the carpet is stretched over a separate cushion or carpet pad, and held in position by a tackless strip positioned around the perimeter of the room (The Carpet and Rug Institute, 1995).

In commercial installations, the use of adhesives in the glue-down method is usually preferred. This method can be used with or without the addition of a cushion under the carpet, or with or without a cushion attached to the carpet. There are two types of installations using adhesives: direct glue-down and double glue-down. Carpet, with or without an attached pad, is adhered directly to the floor in a direct glue-down application. The first step in a double glue-down is the adhering of a separate pad to the floor, followed by the adhering of the carpet over the pad (The Carpet and Rug Institute, 1995).

The carpet industry has also developed some alternative carpet installation systems. One system is based on the interlocking hook and eye tapes familiar to some under the trade name Velcro. A second system used dry adhesive applied to a scrim that is then placed on the floor. The carpet is directly applied to the scrim. The advantages to these systems are the absence of the odors and emissions from the wet adhesives and the ability to "peel-back" the carpet after it is installed (The Carpet and Rug Institute, 1995).

Cushions and Pads

Carpet cushion, also called the pad, is divided into five categories. The first category includes fibers: natural, synthetic, and recycled. The second category is sponge rubber, flat, or rippled. Conventional, grafted, and densified prime polyurethane foam comprises the third category. Bonded foam, made by fusing shredded pieces of polyurethane into a single sheet of material, is the fourth category. The last category is mechanically frothed polyurethane foam, a process whereby polyurethane is applied to nonwoven sheets of material to create a cushion with a firmer feel and a higher density. To meet the needs of the industry, each type of pad can be made for light, heavy, and extra heavy traffic areas (The Carpet and Rug Institute, 1995).

BACKGROUND: ALLERGY AND ASTHMA

Pathophysiology

The purpose of the immune system is to protect the body from invasion by outside cells. Basic to the immune system is its' ability to distinguish the body's own cells from the cells of another origin. When the immune system recognizes proteins or cells from another source it swings into action in an attempt to destroy or neutralize the invading agent. Any agent that triggers the immune response is called an antigen (Schindler, 1992) or an allergen (American Academy of Allergy, Asthma and Immunology [AAAAI], 2000e).

Allergic Disease

Allergy is a term used to describe a group of diseases in which the body undergoes an inflammatory response in response to an environmental agent, referred to as an antigen. Usually the environmental agent, or antigen, is an innocuous substance in the absence of the allergic response (Terr, 1997).

Allergic diseases are classified by the immunological pathways that generate the immune response. A commonly used classification system, by Gell and Coombs, has four types of immunological mechanisms (Brostoff, Scadding, Male, & Roitt, 1991). Using the system of Gell and Coombs, this research is concerned with only one type of immune response, Type I, referred to as Immunoglobulin E (IgE) antibody-mast cell mediator release. Diseases characterized by the Type I response are atopic diseases, commonly referred to as allergic rhinitis, asthma, atopic dermatitis, and anaphylaxis (Terr, 1997). Another characteristic of the Type 1 immune response is its' immediacy, usually occurring within minutes (Brostoff et al., 1991).

Disease Process

Atopic disease, or atopy, refers to an inherited tendency to develop IgE antibodies in response to a variety of inhaled or ingested environmental substances (Terr, 1997). Antibodies belong to a family of large molecules called immunoglobulins. Different types of immunoglobulins perform different functions within the immune defense strategy; Immunoglobulin E (IgE) is responsible for the symptoms of allergy

(Schindler, 1992). Each type of IgE responds to only one specific allergen, which explains why some people are allergic to pollen and others are allergic to pet dander (AAAAI, 2000d).

Another component of the immune system found to be active in the allergic response are granulocytes. Granulocytes are white blood cells with granules containing potent chemicals that the cell sprays onto invading cells in an attempt to destroy them; a process referred to as degranulating. Mast cells are granulocytes found in the lungs, skin, tongue, and the lining of the nose and intestinal tract. Mast cells contain histamine, the inflammatory inducing substance responsible for many allergic symptoms (Schindler, 1992).

After IgE has been produced to respond to a specific antigen, the IgE antibodies attach themselves to the surface of mast cells and await the introduction of the specific antigen to which it responds. When the antigen appears, the IgE captures it and attempts to destroy it by releasing the chemical mediator, histamine, contained within the mast cell. Histamine and other mediators are responsible for the symptoms of an allergic reaction, such as swelling of the tissues, sneezing, wheezing, coughing, and other reactions (AAAAI, 2000f).

Disease conditions

Allergy is the underlying factor in numerous disease conditions, including, but not limited to: asthma, rhinitis ("hay fever"), conjunctivitis (inflammation of the eye), atopic eczema (allergic inflammation of the skin), urticaria (hives), food and drug allergy, and anaphylaxis (a severe, systemic allergic reaction) (AAAAI, 2000c). This thesis will deal only with allergic rhinitis and asthma.

Allergic rhinitis. When allergens contact the lining of the nose, an allergic response, characterized by sneezing, congestion, itchy and runny nose, itchy throat, palate and ears, and itching and watering of the eyes, is triggered. Allergic rhinitis can be triggered by common outdoor allergens, such as weed, grass or tree pollens, and mold. Because the time of year and duration of different pollen and mold seasons can vary, these allergens are referred to as seasonal allergies, or "hay fever". Common indoor allergens such as pet dander, molds, and cockroach and dust mite droppings can also trigger allergic reactions, which are termed perennial allergies (AAAAI, 2000c).

Asthma. Asthma is a chronic lung disease characterized by coughing, chest tightness, shortness of breath, and wheezing. During an asthma attack the chronically inflamed airways become even more inflamed and constricted and breathing more difficult. Asthma can be a life-threatening event. Any exposure that initiates an asthma attack is called an asthma trigger. When an individual with both asthma and allergies is exposed to an allergen, the allergen can act as a trigger. One risk factor for developing asthma is allergic rhinitis and 78% of persons with asthma also have allergic rhinitis. An asthma attack can also be triggered by exposure to irritants, respiratory infections, and exercise. (AAAAI, 2000b).

Medical Treatment

Diagnosis

When an individual seeks help for any health condition, that individual will usually present himself or herself to a healthcare practitioner. The health care practitioner takes a careful history and assesses the clinical, physical, and laboratory information in order to establish the appropriate diagnosis.

Laboratory tests are useful in helping to establish a diagnosis of allergy. Usually these laboratory tests are conducted under the supervision of an allergist / immunologist, a physician specializing in the care of persons with allergies. Since the body develops specific antibodies to specific substances, many allergy tests are designed to detect the presence of these antibodies. Extracts of the proteins of specific allergens are commercially available and standardized to meet the requirements of the U. S. Food and Drug Administration (FDA) and are used to detect the presence of the corresponding antibody in an individual (AAAAI, 2000d). The following are descriptions of commonly used allergy and asthma tests:

Scratch or puncture test. A small amount of allergen extract is lightly scratched or pricked into the skin. If the individual is allergic to that specific allergen, the body mobilizes the allergic response resulting in the release of histamine by the mast cells that rush to the area where the allergen has been detected. The histamine quickly causes a reddened, swollen, and possibly itchy area where the antigen was introduced. The area where the reaction appeared returns to normal shortly, usually within a half-hour (AAAAI, 2000e). This response is also referred to as an immediate wheal and flare, or IgE-mediated response (Lopez & Salvaggio, 1986).

Intradermal test. Depending on the preference of the immunologist, or when the results of a scratch test cannot be clearly determined, an intradermal test may be performed. In this test a small amount of allergen extract is injected under the skin to determine if a reaction takes place (AAAAI, 2000e).

Blood (RAST) test. This test, called a RAST, measures allergen activity associated with IgE antibodies (Ceska, Ericksson, & Varga, 1972). The RAST, or radioallergosorbent test, requires that blood be drawn and sent to a clinical laboratory for testing. This test costs more since it involves drawing blood and the results are not available as quickly. However, it is test of choice when the patient is taking certain medicines or has a skin condition that prevents skin testing (AAAAI, 2000e). While it may be a less sensitive test, it is less likely to produce false positive results (Lopez & Salvaggio, 1986).

Challenge tests. When an allergen extract for the specific antigen to which the individual is suspected of being allergic is not available, and the individual needs to take the specific medicine or food that is under suspicion, a challenge test may be performed. In this case, the individual is asked to swallow or inhale a small amount of the suspected allergen. In the absence of a reaction, the amount may be slowly increased. This type of testing can be very hazardous and is done only when absolutely necessary and under close medical supervision (AAAAI, 2000e).

Pulmonary function tests. Pulmonary function tests are used to measure the severity of an individual's asthma. There are many pulmonary function tests available and they are used to determine the degree to which an individual's airways are obstructed and the degree to which the obstruction is reversible. Most tests involve exhaling into a device that measures how much air a person can exhale in a given length of time and involve the use of spirometers or peak flow meters (Rachelefsky, 1995).

Pulmonary function tests can also include a challenge, such as exercise or the inhalation of an allergen, an irritant, a medication, or histamine. The differences in pulmonary function are then measured. In addition to being used as a diagnostic tool, the pulmonary function tests can be used as the basis for treatment decisions and to monitor responses to treatment (Rachelefsky, 1995).

Treatment

Treatment for allergy and allergen triggered asthma revolves around three main therapies: allergen avoidance, drug therapy, and immunotherapy.

Allergen avoidance. Allergen avoidance is usually the first therapy to be introduced to the allergy sufferer. In fact, this therapy may be introduced before a definitive diagnosis of allergy is made and may be considered to be part of a differential diagnosis, or diagnosis by exclusion. Allergen avoidance is also part of some allergy and asthma prevention programs for persons who have a family history of allergy or asthma (AAAAI, 2000b). One of the primary allergen avoidance methods used is the cases when avoidance is particularly difficult, if not impossible, is encasement. Using this method for endemic allergens, such as dust mites, the allergy sufferer encases the allergen habitat to prevent contact. For example, mattresses and pillows are zipped into plastic cases that provide an effective barrier to allergens.

Persons with allergies are advised to avoid consuming foods to which they are allergic, to avoid contact with substances that are common allergens and are highly allergenic, and to make environmental changes that will reduce the amount of allergen to which they are exposed. Additionally, some recommend the use of air filters, particularly a high-efficiency particulate-type air filter (HEPA) to remove air-borne allergens (Rachelefsky, 1995).

One of the most common recommendations for allergen avoidance, particularly dust mite avoidance, is the removal of carpet from the indoor environment (AAAAI, 2000b; Brostoff et al., 1991; Rachelefsky, 1995;).

Drug Therapy

Antihistamines. Antihistamines act to relieve or prevent the action of histamine, which is released by the mast cells at the site of the allergic reaction. Antihistamines are available in prescription and non-prescription form (AAAAI, 2000a).

Decongestants. Decongestants are used to lessen nasal congestion common to colds and allergies. They decrease congestion by shrinking blood vessels and reducing the amount of fluid available to leak out and cause congestion in an area (AAAAI, 2000a).

Anti-inflammatory agents. One of the major characteristics of asthma is the presence of inflamed airways, which causes them to be over-reactive and more sensitive to triggers such as allergens. Anti-inflammatory drugs reduce the symptoms of asthma by reducing the inflammation and swelling, as well as the level of reactivity, in the airways. Anti-inflammatory drugs can be either corticosteroids (steroids) or not (non-steroidal). These drugs are available by prescription only (AAAAI, 2000a).

Anti-leukotrienes. This is a new group of drugs that counter the effects of potent chemicals called leukotrienes. These chemicals are released by cells involved in causing airway inflammation and are responsible for even more untoward effects in the airways. These drugs fight the inflammatory responses typical of allergic disease caused by these cells and are used in the treatment of chronic asthma (AAAAI, 2000a).

Bronchodilators. These drugs work by opening the bronchial tubes (air passages) so that more air can flow through. These drugs are the “rescue medications” commonly used by people with asthma (AAAAI, 2000a).

Allergen immunotherapy. Allergen immunotherapy is also called “allergy shots” or allergy vaccination. Allergen immunotherapy acts like a vaccination. By exposing the immune system to minute amounts of the allergen to which it reacts, and gradually increasing the amount of allergen exposure, the body gradually builds up an immunity to an allergen to which it previously had an allergic reaction. This regimen may be the treatment of choice when an individual is moderately or severely allergic, reacts to perennial allergens that are not easily avoided, and has not had an adequate response to medications (AAAAI, 2000a).

CHAPTER 3

REVIEW OF LITERATURE

A review of the literature reveals that there are several types of indoor air quality problems within buildings. In this chapter, the types of indoor air quality problems are described and the mechanisms by which building-related illnesses are caused are identified. The role of carpet in indoor air quality and how carpet affects the illness causing mechanisms are illustrated. House dust mites can contribute significantly to the poor quality of indoor air in some buildings, acting by an immunological mechanism. Mites and their habitat are characterized. Studies of carpet and dust mites are included, and a possible rationale explaining a cause for the diversity of research findings on carpet and dust mites is presented.

Indoor Air Quality

"The quality of air is the most essential determinant of the quality of life. As people in temperate climates spend an average of 80-90% of their lives indoors, this refers mainly to the quality of indoor air" (Jantunen, Jaakkola, & Krzyzanowski, 1992, p. 1). Persons who live in urban settings, infants, elders, and persons with chronic diseases probably spend proportionally even more time inside (United States Environmental Protection Agency [USEPA], 1998). Americans spend between 30-60% of their lives in their homes eating, relaxing, working, and sleeping (Hamilton, Chapman, Platts-Mills, & Adkinson, 1992).

Woods (1988) reports that the conflict between maintaining acceptable quality of indoor air and the need to conserve energy is as old as people's desire to seek shelter in permanent structures. Vent holes were used in the roofs of indigenous architectural structures to remove pollutants created by the building of small indoor fires to warm the interior. Prior to the invention of glazing, people could not introduce natural light without also dealing with problems of uncontrolled ventilation (Woods, 1988).

Unacceptable indoor air quality was noted to be a significant problem during the Middle Ages. In an attempt to provide adequate ventilation for his subjects, King Charles I of England established one of the earliest laws regulating ventilation. He ruled that no house could be built with a ceiling lower than 10 feet and windows must be higher than they were wide (Woods, 1988).

Public health practitioners have known for decades that contaminants within many buildings were capable of causing and spreading disease. Scientific experiments on ventilation requirements conducted in the 1920s and 1930s led to the estimate of a need for 5-30 cubic feet of outside air per person, per minute, for odor control. These estimates were the basis for the adoption of ventilation standards for natural and mechanical ventilation by the American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) in 1973 (Hodgson & Morey, 1989).

In the 1970s, as a result of the Middle East oil embargo and what was generally perceived to be a worldwide energy crisis, much greater emphasis was placed on conserving energy. Since approximately one-third of all energy was being used in heating and cooling buildings, buildings became a major focal point for energy conservation. Older buildings were insulated and caulked to prevent the escape of conditioned air and new buildings were built to be “tighter”. Some new buildings were built without operable windows and were completely dependent on mechanical systems for ventilation.

In addition to reducing the accidental leaking of outside air into buildings, there was also a deliberate reduction of mechanical ventilation rates in order to save energy. In 1981, ASHRAE reduced the minimum recommended ventilation rate in commercial buildings from 15-25 cubic feet per minute (cfm) to 5 cfm in a new ASHRAE Standard 62-1981 (American Society of Heating, Refrigeration and Air-Conditioning Engineers {ASHRAE], 1981). By 1989, the increasing number of reports of discomfort and sickness in commercial buildings caused ASHRAE to increase the supply of outside air from 5 cfm to 15-20 cfm per person in ASHRAE Standard 62-1989 (ASHRAE, 1989). However, the newer ASHRAE standard did not recommend the monitoring of the quality of indoor air or the performance of the building’s mechanical systems, and the prescribed minimum ventilation standard soon became the design maximum (Harriman, 1993).

Types of Indoor Air Quality Problems in Buildings

In an informational publication designed for health care professionals, the USEPA (1999) observed that the individual presenting himself to a health care professional for treatment of a condition with environmentally associated symptoms is more apt to have been exposed to airborne substances indoors, rather than outdoors. Rather than focusing environmental laws on the amount of contact persons have with pollutants, in the United States, the laws are focused on seeking to control the release of potentially dangerous waste products into the air and water (Ott & Roberts, 1998). Ott and Roberts (1998) observe that in two communities with large chemical processing plants, the levels of 11 volatile organic compounds were higher inside than they were outside.

In 1989, the Director of the National Institute for Occupational Health and Safety issued a report describing the group's activities with regard to indoor air quality from 1971 to 1989. During that period, 529 buildings were evaluated. Several building types were included: government and business office buildings, 80%; schools and colleges, 13%; and health care facilities, 7%. The primary types of pollution problems were attributed to: inadequate ventilation, 53%; indoor air contaminants, 15%; outside air contamination, 10%; microbial contamination, 5%; and unknown, 13% (Oliver & Shackelton, 1998).

Any illness caused by an indoor environment is called a *building-associated illness*. There are two categories of building-associated illness: *sick building syndrome* and *building-related illness*. Illness with a long latency period (for example, the lung cancer caused by radon) have been excluded from this classification (Seltzer, 1994).

Within the community of health care providers, objective patient data is obtained through direct observation, clinical examination, laboratory analysis, and radiological studies. Subjective patient information is obtained as the individual describes the onset, the course, and the character of the problems as the individual has perceived it to be (Anderson, 1998).

Sick Building Syndrome

Sick building syndrome is difficult to understand because the pathological mechanisms that cause the syndrome are obscure. Additionally, the complaints voiced by sufferers are predominantly subjective and, therefore, difficult to measure. Complaints include neurobehavioral symptoms (headache, memory loss, dizziness, and depression), respiratory complaints (shortness of breath, coughing, and chest tightness), and symptoms of mucous membrane irritation (burning eyes, nose, throat, and sinus) (Seltzer, 1994).

There have been numerous associations between inadequate ventilation and the symptoms of *sick building syndrome*. There is inadequate data to demonstrate a cause and effect relationship between ubiquitous chemical compounds and subjective symptoms experienced by sufferers (Seltzer, 1994). Symptoms of *sick building syndrome* begin when the person enters the building and end when he or she leaves (Terr, 1994).

<u>Multiple Chemical Sensitivity.</u> The term *multiple chemical sensitivity* was coined in 1987 to describe a condition that is related to low-level contact with chemicals that are ordinarily considered safe and do not cause illness in the rest of the population. This condition has also been called "environmental illness," "total allergy syndrome," "cerebral allergy," "twentieth century disease," and "chemically induced immune dysregulation." The illness is always subjective and symptoms are non-specific (malaise, fatigue, disorientation, and poor memory) and often results in occupational and domestic disability (Terr, 1994).

Those who suffer from *multiple chemical sensitivity* are often unable to tolerate a wide variety of drugs, foods, and environmental chemicals. Intolerance in these cases is different from usual immunological sensitivities in that exposure to the suspected allergen produces no objective evidence of target organ inflammation. Additionally, many of the symptoms evoked by exposure to specific allergens do not correspond to known toxicities of the particular agents or do not correspond to known allergic reactions. Persons suffering from *multiple chemical sensitivities* are often treated by practitioners who refer to themselves as Clinical Ecologists (Terr, 1994).

<u>Building-Related Illness</u>

Building-related illnesses are those that are characterized by a clear association between exposure to indoor environmental factors that produce well characterized human illnesses. The illness can be related to clinical and laboratory findings based on well-accepted principles of pathophysiology. There are four mechanisms by which building-related illnesses are caused: toxic, irritant, immunological, and infectious. Two or more mechanisms may be operating at one time to cause illness in an individual (Seltzer, 1994).

Toxins. *Toxins* are poisons that alone, or in combination with another agent, cause a deleterious effect in a biological system. Toxins seen in building interiors include lead, radon, pesticides, and by-products of combustion (Seltzer, 1994).

Irritants. *Irritants* often cause harm because of their extreme pH, because they act as desiccants, or through organ over-stimulation. Examples of irritants seen in buildings are loud noise, strong smells, volatile organic compounds in cleanings products, cigarette smoke, and by-products of combustion (Seltzer, 1994).

Immunological agents. *Immunological* etiologies of building-related illnesses include such agents as fungi, bacteria, insects and insect parts, protozoa, and possibly chemicals and endotoxins. While large amounts of allergens are usually required to initially sensitize a genetically susceptible individual, only minute quantities are required thereafter to produce an allergic response. Allergic rhinitis and asthma are common examples of this mechanism at work (Seltzer, 1994).

Infectious agents. Mechanical ventilation systems that are not properly maintained have been associated with several outbreaks of *infectious* disease. The most published case, and for many people the first indicator of possible problems with the quality of indoor air, was the 1976 outbreak of Legionnaire's Disease in Philadelphia. A previously unrecognized bacterium, later named *Legionella pneumophilia*, in the hotel's ventilation and humidification system caused 182 cases of pneumonia and 29 deaths (Oliver & Shackleton, 1998). Other diseases known to be spread through building systems are influenza, measles, and tuberculosis (Seltzer, 1994).

Indoor Air Quality Problems in Homes and Residential Settings

Studies have shown that the air inside our homes can be less healthy than the air in commercial buildings (Beer, 1997). In fact, "… the same pollutants covered by environmental laws out-doors are usually found at much higher levels in the average

American residence. … Of the hundreds of air pollutants covered under existing U. S. laws, only ozone and sulfur dioxide remain more prevalent outdoors” (Ott & Roberts, 1998, p. 90).

Some people are more susceptible than others to problems caused by contamination of the indoor air. Those persons are infants, young children, and elders as well as those with chronic cardiovascular or pulmonary problems and those with suppression of the immune system (USEPA, 1999a).

Role of Carpet in Indoor Air Problems

While carpet may be associated with indoor air quality problems, little attention has been paid to the possible effects that differences in carpet construction could cause. Unless the study is performed by textile scientists, carpet is usually considered to be a generic entity. When one considers the possible number of combinations of variables within individual carpets, it would seem that individual carpet microenvironments could be considerably different and the possible differences could explain the diversity of research findings with regard to mites and their presence in carpet.

The perception that carpet has an adverse effect on indoor air quality is not unusual. In a survey of 440 professional interior designers in seven Rocky Mountain states (Tremblay, Peng, Kruel-Froseth, & Dunbar, in press), 74% of the designers responded that carpet “always” or “frequently” affects indoor air quality and therefore, the health of the occupants of the carpeted environment. An interesting corollary was that 90.4% of the same designers felt that they did not have adequate information on indoor air quality.

Stories of the indoor air problems in the Environmental Protection Agency Building in Washington, DC and the suspected role of carpet were widely covered. Subsequent findings exonerating carpet received less notice and some authors appear not to have received the information. As a result, there are still reports of toxic effects of carpet exposure in the literature and the recommendation to avoid carpet because of these unproven associations. Some authors recommend carpets made of natural fibers with no treatments to reduce soiling, and no antimicrobial or insect preventative treatments because they are more natural (Baker, Elliot, & Banta, 1998).

Carpet and Toxins

In a review of previous research done in the area of sorption of air pollutants onto textiles, one group of researchers observed that several interior textiles are capable of sorbing air pollutants and most research has been conducted on the ability of carpets and wool fibers to sorb sulfur dioxide (SO_2). These researchers have called for more research in this area and for a system of classifying textiles according to their abilities to sorb air pollutants (Walters, Goswami, & Vigo, 1983).

Anderson Laboratories Study. In the summer of 1992, Anderson Laboratories released press reports, and subsequently testified before Congress in November of the same year, that their labs had been using mice to test chemical emissions from carpet and that the mice had fared badly in the tests. The mice were reported to have suffered pulmonary and sensory irritation and signs of neurotoxicity and then died after having been exposed to air from heated chambers containing carpet samples (Dyer, 1994).

The immediate concern for the public health caused the EPA and the Consumer Product Safety Commission (CPSC) to initiate an effort to attempt to replicate and understand the reports from the Anderson Laboratories. The EPA assembled a research team including scientific researchers from the EPA, several Office of Research and Development Laboratories, contractor laboratories (including Anderson Laboratories) and the CPSC. More than a year later, no researcher had been able to reproduce the findings of Anderson Laboratories and more than 50 experiments by the EPA had reported no carpet-related toxicity in mice (Dyer, 1994).

In a legal ruling, the standard for accepting expert witness testimony and acknowledging it to be scientifically valid is referred to as *Daubert*. In order for a scientific experiment or technique to be considered reliable, meet the standard of *Daubert*, and be accepted in the court system, it must meet the following requirements:

- The technique must have been tested and independently validated or replicated;
- The technique must have been subjected to peer review and publication;
- The technique must be generally accepted by the scientific community; and
- Other factors should be considered (Ruffin v. Shaw Industries, 1992).

Using the standard of Daubert, the evidence from Anderson Laboratories was not considered scientifically valid and was not admissible in the courts of North Carolina (Ruffin v. Shaw Industries, Inc., 1992) and Vermont (Sands v. Dorsett Carpet Mills, Inc., 1994).

Carpet and Irritants

Carpet emissions will vary depending on the composition of the carpet and the construction method used to create it. The volatile organic compounds (VOCs) emitted from a new carpet are present in trace or very small quantities. Carpet emissions naturally decline as the VOCs are emitted from the carpet and after seven days will have fallen below detectable levels (Dietert & Hedge, 1996).

In an attempt to determine what effects VOCs had on human health and the indoor environment, Cornell University researchers conducted a literature review covering 416 scientific publications related to carpet and carpet emissions. They concluded that, "… under normal environmental circumstances, VOC emissions from new carpets are sufficiently low such that they should not adversely affect indoor air quality or pose significant health risk to people" (Dietert & Hedge, 1996, p.633).

Carpet emissions increase when the temperature of the carpet is increased, though substantial increases occur only when the air temperature is increased by enough to cause the carpet to begin to bake (Dietert & Hedge, 1996). This is the rationale behind suggesting that after new carpet is installed, but before residents occupy the space, the temperature and ventilation of the space be increased. This procedure is often called "bake out" and is carried out in order to reduce the potential for irritation caused by VOCs present in new carpet. Alternately, new carpet can be unrolled and aerated in the warehouse before installation. In either situation, the rate of ventilation should be increased to full capacity for 48-72 hours (The Carpet and Rug Institute, 1995).

Formaldehyde is an irritant, and because it is highly soluble in water, it affects the mucous membranes of the throat, nose, and eyes and has been known to be an asthma trigger (Samet, 1990). Formaldehyde has not been a part of the manufacturing of new carpet in the United States since 1983 (The Carpet and Rug Institute, 1995). Emissions tests on new carpets show that levels of formaldehyde are typically lower than levels in common materials, such as paper plates, men's polyester/cotton shirt, and particleboard. In fact, some research findings indicate that carpet may absorb formaldehyde from other indoor sources (Dietert & Hedge, 1996).

In 1991, the carpet industry, in conjunction with the American Lung Association, the Environmental Protection Agency (EPA), the Consumer Product Safety Commission, and others, began to study a program under which new carpet would be tested for VOCs immediately after production. As a result of these consultations, manufacturers are able to submit their carpets to an independent testing laboratory to be tested in an environmental chamber initially developed by the EPA. If the carpets do not exceed established emission levels, they are allowed to affix the Carpet and Rug Institute Indoor Air Quality (CRI IAQ) Carpet Testing Program green label (The Carpet and Rug Institute, 1995).

Carpets and Immunological Agents

Carpet has been acknowledged to be a collector, or sink, for a variety of particles that could become airborne (Cole, Foarde, Leese, Franke, & Berry, 1993). House dust mites are endemic and carpet should not be considered the primary means of exposure. However, carpet does provide a reservoir for infestation and a generation source that becomes airborne during vacuuming. Intensive vacuum cleaning reduces the amount of allergen in the carpet but the use of vacuum cleaners with inadequate filtration is to be avoided since this is one of the only ways to get the allergen airborne and available for inhalation. Fortunately, house dust mite allergen is a large and relatively heavy particle that settles quickly (Woodcock & Custovic, 1998).

It is possible to kill mites in carpet with chemicals (acaricides), by freezing, or the use of steam but these methods are unlikely to prove time effective (Woodcock & Custovic, 1998). Unfortunately, killing live mites does not remove the allergen from the environment. Additionally, re-treatment is always necessary due to the likelihood of re-infestation (Strachan, 1998). Air filters and ionizers are of little benefit since the dust mite allergen does not stay airborne for long periods (Woodcock & Custovic, 1998).

Carpet is also a major reservoir for pet dander in homes with household pets (American Thoracic Society, 1997). In fact, pet allergens are transported on individual's clothing and are present throughout most homes, including homes without pets, and in public spaces (Woodcock & Custovic, 1998).

Recommendations regarding carpet from professionals concerned with allergens in the indoor environment vary considerably. One group of researchers found that carpet is a collector of allergenic particles that could potentially become airborne and sensitize individuals and also provides a potential source of indoor microbiological contamination. However, they found that contamination needed to be "extensive" to affect the quality of indoor air (Cole et al., 1993). Other researchers viewed carpet as an allergen reservoir and recommended the removal of all carpets as an active strategy to control the growth of allergens in the home (Marks et al., 1994; Woodcock & Custovic, 1998).

It is important to note that very little research has been conducted on the effect of the type of carpet on the development of dust mite allergen. Studies on the effect of floor type on the number of mites present in floor dust have had mixed results. In a series of studies carried out in Norway, Dybendal and others (Dybendal, Hetland, Vik, Apold, & Elsayed, 1988; Dybendal, Vik, & Elsayed, 1989, 1990; Dybendal, Wedberg, & Elsayed, 1991; Dybendal & Elsayed, 1994) studied floor types and the relationship of floor types to numerous allergens. In the first study, no qualitative or quantitative difference was found between floor type, carpeted and smooth, and the allergen content of the dust in the schools studied (Dybendal et al., 1988). In his second study, Dybendal, et al. (1989) found, with the exception of codfish and hen egg white, no statistically significant differences in the presence of allergens in dust extracts from carpeted and smooth floors. Unfortunately, these samples were collected in December and January when pollen and dust mites samples would be expected to be very low. The next study, attempted, unsuccessfully, to denature allergenic proteins using cleaning products (Dybendal et al., 1990). In the 1991 study, Dybendal, et al., found a significant difference in the amount of allergen vacuumed from carpeted and smooth floors, in direct contrast with his earlier studies. In 1994, Dybendal and Elsayed compared carpeted and smooth floors in schools and homes and determined that some allergens differed, but mite allergen was more prevalent in homes and on carpeted floors of schools and homes. Unfortunately, school samples were collected in February and home samples in April, which could account for some of the difference (Dybendal & Elsayed, 1994). It is important to note that, even though this group of studies always included carpet as a variable, the carpet was never described, nor any of the characteristics of the carpet included.

Additionally, one group of researchers (Gotzsche, Hammarquist, & Burr, 1998) conducted a controversial meta-analysis of randomized trials of the effect on asthma of various physical or chemical measures to control mites in the environments of persons sensitive to mites. They concluded, “Current chemical and physical methods for eradicating mites or reducing exposure to mites seem to be ineffective and cannot be recommended as prophylactic treatment for asthma patients who are sensitive to mites” (Gotzsche et al., 1998, p.8).

Carpet and Infectious Agents

There have been reports of an association between carpeting and Sick Building Syndrome (Norback & Torgen, 1989). One of the more remarkable associations occurred in 1988 when the media began to report on a case of Sick Building Syndrome in the headquarters building of the U. S. Environmental Protection Agency (EPA). New carpet had been installed in the building and numerous EPA employees became ill (Mitchell, 1996) and some were reported to be permanently disabled with Multiple Chemical Sensitivities (National Federation of Federal Employees v. EPA, 1990). Subsequent study by EPA scientists and independent researchers revealed that the EPA building had a history of indoor air quality problems. The building suffered from a poor ventilation system and inadequate maintenance, as indicated by “heavy infestations of fungi (including mushrooms) on many surfaces including some carpet and heavy accumulations of dirt and fungi in the air handling systems due to poor maintenance” (Mitchell, 1996, p. 25).

“Fungi are a diverse group of organisms; some are infectious agents… fungi also produce allergens and toxins; exposure to these can have deleterious health effects. Rather that serving as a refuge, however, many indoor environments foster the growth of fungi that are adapted to living on surfaces and to using certain common building materials as a substrate (Horner, Lehrer, & Salvaggio, 1994, p. 551).

Fungi are known as mold, mildew, yeast, mushroom, truffle, rust, and smut. The essential requirements for fungal growth are oxygen, suitable temperature, a source of food (substrate), and moisture. It is impossible to eliminate oxygen from the same environment in which people are expected to live. Fungi grow well within the same range of temperature that people typically prefer indoors. Many building materials provide a suitable substrate for fungal growth. Growth of fungi can be inhibited with the addition of fungicides into a substrate and this is effective in preventing growth, but great care must be taken not to harm the human inhabitants of the environment (Horner et al., 1994).

In a study conducted in damp homes in The Netherlands, Verhoeff and his associates (1994) found that the only consistently significant variable effecting the number of colony forming fungal units in floor dust was the type of flooring. Carpeted floors had significantly higher numbers of colony forming fungal units than did smooth floors. Carpets in this study are described as "wall-to-wall".

Schober (1991) studied the presence of fungi in dust from carpets and dust from upholstered furniture in The Netherlands. While observing that the development of fungi is primarily dependent on the availability of moisture, and the fact that ground floor rooms are usually more humid than rooms on higher floors, no statistically significant difference could be found in numbers of spores between ground level floors and higher level floors. When comparing the climate in carpet and the climate in upholstered furniture, the climate in upholstered furniture is known to be drier and more closely related to the environment in the room. The study found higher numbers of fungal species in dust from carpet than from upholstered furniture (Schober, 1991).

Fungi can be a primary allergen through exposure to the spores or vegetative cells, or persons can have an allergic response to metabolites of the fungi (Burge, 1989). Additionally, fungal metabolites contribute VOCs that may have been incorrectly identified in the past. In a study of VOCs from fungal contamination, researchers concluded:

> Many of the VOCs that were identified in the volatile gases evolving from the cultured fungi commonly occur indoors. Generally, these VOCs are identified as

> originating from solvent-based building materials and cleaning products. This study indicates that these VOCs also can be generated by fungi as metabolic products (Bayer & Crow, 1994, p. 165).

In other words, the VOCs that we have attributed to building materials may actually be the metabolic byproducts of organisms using the building materials as a substrate.

Antimicrobial carpet finishes. Carpet installed in health care facilities is usually of an antimicrobial type to prevent the growth and spread of microorganisms. Resistance to biological growth has been engineered into nylon fibers by adding antimicrobial agents into the polymer solution or one of the early stages of production (Yeager, 1988).

There are two types of antimicrobial treatments given to fibers: unbound and bound. Unbound agents must diffuse from the textile and be consumed by the organism. Once consumed it acts as a poison and interferes with the life sustaining processes of the organism. Unbound agents are "used up" because they are diffused from the fibers and eventually cease to be effective. Bound antimicrobials are bound to the fiber and physically interrupt the cell membrane causing it to cease to function. These agents are effective against bacteria, molds, mildew, fungi, yeast, and algae (Hatch, 1993). In an award winning study on the effectiveness of antimicrobial carpet, the Auburn University Student Chapter of the American Association of Textile Chemist and Colorists (1987) determined that the use of antimicrobial carpet can reduce the growth of microbes by 75-99%.

Moisture

There are two ways that moisture can enter a building. The first is externally through a penetration of the building envelope, as in a leak in the roof, windows, or doors. The second way moisture can enter a building is an internal leak or overflow of pipes, tubs, basins, or appliances.

In some climates, condensation on concrete floors in basements or ground level floors can be a problem. This is the reason that vapor barriers are used and why it is generally recommended that carpet not be applied to these types of concrete floors. The carpet will absorb the condensation and provide an excellent habitat for the growth of microorganisms (USEPA, 1999a).

The climate for carpet on floors has been proven to be different than the climate for upholstered furniture. The climate for upholstered furniture is dryer and more like the general climate in the room. Consequently, the numbers of fungal species in carpet dust are higher than those from upholstered furniture (Schober, 1991).

Damp homes can be problematic because some may find the presence of visible mold and its accompanying odors to be offensive. Additionally, the dampness allows the proliferation of house dust mites. Both mold and dust mites are allergenic. Unfortunately, it is difficult to collect evidence determining which residential design features directly affect the ambient indoor environment and consequently allergen levels and human respiratory health. However, some researchers conclude that evidence is beginning to suggest that designing homes to reduce indoor humidity may contribute positively to the health of persons who suffer from allergic conditions (Peat, Dickerson, & Li, 1998).

In fact, other researchers believe:

> It is, then, highly probable that the presence of mold, dampness and related conditions in homes are contributing to morbidity. However, we do not have substantial documentation of the extent of these problems within U. S. housing stock. …Because fungi and bacteria are ubiquitous in air and on natural substrates, they are always available to attack any suitable material as soon as moisture and temperature conditions are appropriate (Spengler, Burge & Su, 1991, p.14-15, 16).

<u>Cleaning</u>

There are four methods of cleaning carpets and they are dry extraction, dry foam, wet shampoo, and hot water extraction.

<u>Dry extraction.</u> This system of cleaning is also known as absorbent compound or absorbent powder cleaning. In this method, soil-extracting particles are spread over the carpet structure and rubbed into the pile layer using a machine or by hand. The soil-extracting particles are composed of a solvent and a water-based cleaning fluid or detergent which absorbs the soil and can then be vacuumed away. The advantage of using this method is that the carpet is not wetted (Yeager, 1988).

Dry foam. This method of cleaning is also known as aerosol cleaning and uses a water-based shampoo in the form of a foam cleaner. The foam is sprayed on the carpet and worked into the pile using mechanical brushes or sponges. Soil is subsequently removed by vacuuming. While this method has the advantage of not over-wetting the carpet, it is not as thorough as other methods of carpet cleaning (Yeager, 1988).

Wet shampooing. Wet shampooing, also known as the rotary brush method, involves the use of liquid detergent solution and brushes to drive the cleaner into the pile from which it is subsequently removed by a wet vacuum. In the process of working the cleaning solution into the pile of the carpet, the pile may become distorted. The danger of over-wetting the carpet also exists. Also, any remaining soil-shampoo residue left in the carpet may accelerate the subsequent accumulation of soil (Yeager, 1988).

Hot water extraction. Often called steam carpet cleaning, this method uses hot water and not steam in cleaning. Hot shampoo solution is driven into the carpet by high-pressure jets and then removed by the wet vacuum that is part of the same machine. No brushes are used and the pile yarns, therefore, suffer minimal distortion. To avoid having stains set by the heat of the water, they should be removed before cleaning. Care should be taken to remove all of the soil-shampoo solution to avoid accelerated resoiling of the carpet (Yeager, 1988).

Allergy and Asthma

Incidence

In an editorial, the editors of a medical journal concerned with medical issues related to allergy and asthma noted:

> There is now convincing evidence that the prevalence of asthma and of other allergic disorders has steadily increased in the last decade, especially in children who live in affluent countries. Although this trend of an increasing prevalence of allergic disease is undisputed, the actual size of the increase has been difficult to measure accurately because media attention has increased at the same time as the increasing prevalence and has therefore increased awareness (Editorial, 1994, p. 797).

Allergy

Based on the results of a skin test survey, The American Academy of Allergy, Asthma and Immunology (AAAAI) has noted that 40-50 million Americans have allergies (AAAAI, 1999).

Allergic Rhinitis. The AAAAI has estimated that 9.3% of the population have allergic rhinitis, commonly known as hay fever (AAAAI, 1999).

Asthma. According to the Centers for Disease Control and Prevention (CDC) (Mannino et al., 1998), there is a 75% increase in self-reported prevalence of asthma in the United States from 1980, with a rate of 30.7 per 1000, to 1994, with a rate of 53.8 per 1000. During the same time period, the greatest proportional increase, a 160% increase, was among children less than 5 years of age. The trend in increased rates was evident among all race strata, both sexes, and all age groups. Asthma was the most frequently diagnosed illness in hospitals in the United States in 1993. In discussing their surveillance report on asthma, the CDC researchers note, “National statistics indicate that asthma prevalence and mortality have increased in recent years, despite numerous advancements in the diagnosis and treatment of asthma” (Mannino et al., 1998).

In the period 1979 to 1997, the age-adjusted asthma mortality rate for white females increased by 63%, by 25% for white males, by 95% for black females, and by 68% for black males (National Center for Health Statistics, 1999).

Worldwide Prevalence

After reviewing more than 100 medical research studies related to allergic rhinitis, allergy and asthma, Sly (1999) concluded that the increased prevalence of asthma is not limited to the United States but is a worldwide phenomenon. For example, a study of prevalence in Great Britain noted an increased prevalence of allergic rhinitis in 16 year olds. Children born in Great Britain in 1958 had a prevalence rate of 12% at age 16 and children born in 1970 had a rate of 23% at the same age (Sly, 1999).

Cost to Society

Financial

In an attempt to determine the health care costs of treating persons who suffer from asthma, Weiss, Gergen and Hodgson (1992) used 1985 data from the National

Center for Health Statistics to project 1990 costs from estimates of direct medical expenditures and indirect costs. Additionally, 1985 costs were compared to projected 1990 costs. Direct costs were identified as those for inpatient hospitalization, hospital outpatient services, emergency room services, physician services, and medications. Direct costs for the treatment of persons with asthma in 1985 were almost $2.4 billion, as compared to 1990 projected costs of $3.6 billion. This represents an increase in direct expenditures of 53% from 1985 to 1990 (Weiss et al., 1992).

Indirect costs include time lost from school and work and mortality losses. Indirect health care costs for treating those with asthma in 1990 were projected to be $6.2 billion, a 22.7% increase over 1985 costs. Weiss, et al. (1991) noted that while asthma is often considered to be a mild chronic illness, 43% of the costs of caring for persons with asthma are those associated with hospitalization, emergency room use, and death.

Environmental Recommendations

Some (Bonini, Magrini, Rotiroti, Ronchetti & Onorati, 1994) believe that the pathogenesis of human disease can be seen as an example of the interaction between an individual's genetic predisposition to develop a condition and environmental factors. The disease of the individual is determined by the relative prevalence of each factor. For example, if a condition were caused only by genetic factors, the condition will develop regardless of type of environment in which the individual lives. On the other extreme, if a condition were caused only by the environment, without regard to the genetic susceptibility of the individual, each of us would be equally likely to be made ill by the condition. These researchers believe that preventative measures are most useful in diseases in which both genetic and environmental factors are relevant (Bonini et al., 1994). Allergic diseases are such conditions.

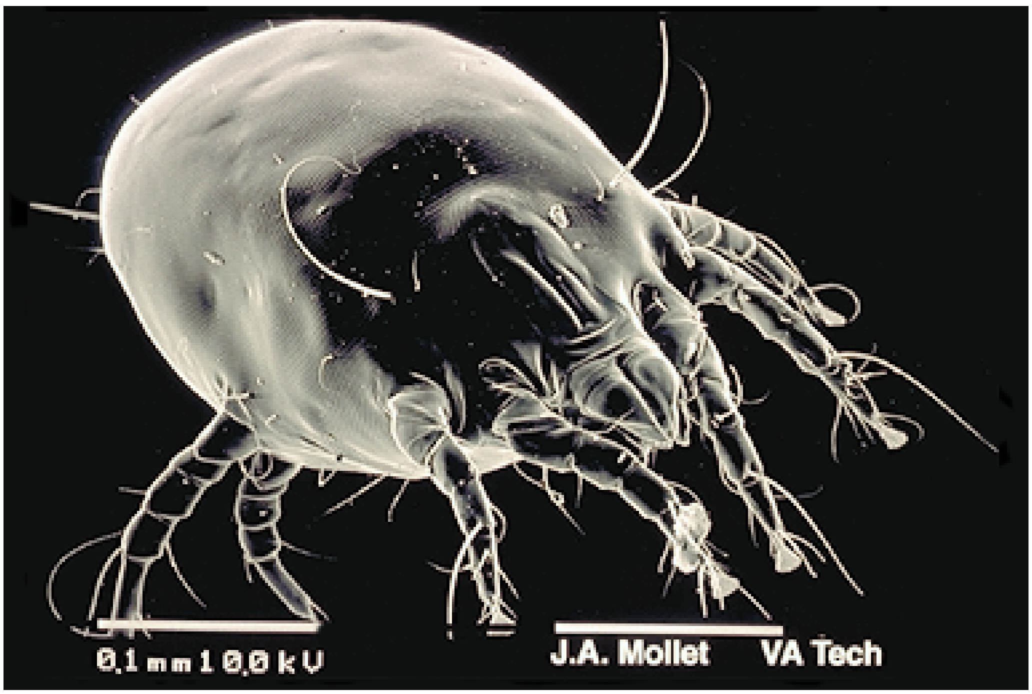
Mites

Description

"Although tiny themselves, mites belong to the largest and most impressive lineage of animals, the arthropods. Within the Arthropoda, mites are the most diverse representatives of an ancient lineage…" (Walters & Proctor, 1999, p. 3). Animals within the phylum Arthropoda are distinguished by having a non-living external skeletal covering composed of chitin (a complex sugar bound to a protein). The bodies of arthropods are usually segmented and the segments have pairs of appendages with joints (Arthropod, 1999).

Figure 1

American House-dust Mite (*Dermatophagiodes farinae*)



Within the phylum Arthropoda there are four subphyla: Trilobita (which became extinct 286 to 245 million years ago), Chelicerata (which are mostly terrestrial and include spiders, scorpions, ticks, and mites), Crustacea (which are mostly marine animals, including crayfish, crabs, and shrimp), and Uniramia (which are mostly terrestrial and include insects and long-bodied arthropods such as centipedes and millipedes) (Encyclopædia Britannica, 1999). The chelicerate body is different from other arthropods is several ways. First, it does not have a separate head, but rather, an anterior body region, the prosoma, that performs the same functions as a head, such as sensing and feeding. Second, it lacks the sense organ common to most other arthropods, the antennae. It also does not have the usual mouth comprised of mandible and maxillae.

Instead, mites and other chelicerate arachnids have evolved their anterior appendages into a pincer-like mouthpart, the chelicarae, in front of the oral opening. The second pair of appendages, the pedipalps, are behind the chelicarae and function to both sense and handle food. Both the chelicarae and the pedipalps are part of the prosoma. The posterior part of the body, the opisthosoma, is involved in digestion, gas exchange, and gamete production. The opisthosoma has four pairs of jointed legs attached to it (Walters & Proctor, 1999).

Chelicarata have traditionally been divided into three major groupings. The first two groupings, together referred to as the Merostomata, are entirely marine creatures and almost entirely extinct. The third grouping of Chelicarata, the Arachnida, include terrestrial scorpions and arachnids. The subclass of Arachnida that includes mites and ticks is called Acari. Acari are distinguished from other arachnids by the fusion of body segments into a single body. Acari are usually fungal-feeders or parasites (Walters & Proctor, 1999). It is possible to divide the subclass of acarids into three orders, comprised of six suborders and approximately 428 families (Arthropod, 1999).

Dust mites are the most infamous members of the family Pyroglyphidae; one of the 14 species reported in house dust from various parts of the world. One of the characteristics of this group is their close association with and living in the presence of birds and mammals. The three most common species of dust mites worldwide are *Dermatophagoides pteronyssinus, Dermatophagoides farinae*, and *Euroglyphus maynei* (Walters & Proctor, 1999). Mites are classified by the location of their breathing orifices. Astigmata have no breathing orifices and respire through their integument. This group is much more dependent on relative humidity for their survival (J. Mollet, personal communication, May 22, 2000).

In the United States, there are two principal species of house dust mites. They are the American dust mite, *Dermatophagoides farinae*, and the European dust mite, *Dermatophagoides pteronyssinus* (Mollet, 1995).

> They live in our rugs, furniture, mattresses, bedding, and other areas that accumulate organic detritus and maintain a high level of humidity. Pyroglyphid mites feed on cast skin flakes (*derma* = skin, *phagos* = eat), hair, and other

detritus, together with the microbes that grow on this minute refuse. They are the most important source of allergens in house dust. Allergens produced by these mites cause severe allergies, rhinitis, eczema, and asthma that affect 50-100 million people worldwide. These allergens are contained primarily in dust mites faeces. They are dry pellets 20-50 µm in diameter that are covered with a peritrophic membrane (a membrane produced in the gut of the mite). On average, about 20 pellets are produced by each mite each day and they readily become airborne. Other allergens are present in the skin of the mite; so exuviae and bits of dead mites also cause reactions (Walters & Proctor, 1999, p. 227).

The phrase 'dry as dust' suggests that house dust may be an arid environment for tiny animals. Dust mites have an ingenious solution to the problem of water balance (shared by numerous other Astigmata). A small gland opening at the base of the first pair of legs (supracoxal gland) secretes a solution of sodium and potassium chloride into a gutter that runs to the mouth opening. The salt solution is hygroscopic and absorbs water from the atmosphere, down to a species-specific critical threshold of relative humidity (often 70-75% RH at 25°C). At lower humidities, the solution crystallizes and blocks the gland opening, preventing water loss. So, dust mites obtain water from the atmosphere at relative humidities above the critical threshold but are unable to 'drink' at lower relative humidities and will desiccate and die if low RH is maintained for very long. Any conditions that help to maintain high humidities may encourage house dust mite populations (Walters & Proctor, 1999, p. 228).

There are five developmental stages in the life of the *Dermatophagoides pteronyssinus*, *Dermatophagoides farinae*, and *Euroglyphus maynei*. They are egg, larva, protonymph, tritonymph, and adult. Each subsequent life stage adds morphological structures not present in previous stages (Arlian, 1989). Pyroglyphid dust mites reproduce sexually with adult males mating with female tritonymphs and adult females. After mating, adult female mites will lay eggs at a rate of 1-3 per day, depending on environmental conditions (Hart, 1998). Under optimal conditions (75% RH and 22-26°C) 23-30 days are required for the mite to develop from egg to adult. Protonymphs appear to be more desiccation resistant and are able to survive longer periods of low relative humidity. Some experts believe that mites in this developmental stage serve as a source of breeding mites until the time when living conditions improve (Arlian, 1989).

Where they live Within the United States, in humid geographic areas, such as New Orleans, Galveston, and Memphis, nearly 100% of homes may have mites present and the density of mites within a home could be as high as 18,000 mites per gram of dust. In drier climates and higher elevations, such as Denver, mites are present in fewer than 10% of homes and the concentration of mites is usually below 100 mites per gram of dust. In temperate climates, mite density follows a seasonal cycle which corresponds to relative humidity with highest mite levels in summer and early fall, seasons characterized by high humidity (Arlian, 1989).

The greatest concentrations of house dust mites within homes are usually in areas of high use, such as beds, upholstered furniture, and carpeted floors in areas where humans shed skin. While mite density varies within areas within a home, seasonal variations occur within all areas (Arlian, 1989).

Eradication of Mites

House-dust mites have no significant predators and competition for food or territory does not seem to play a role in the populations of mites (Hart, 1998). However, mites can be killed by using an acaricide. The active ingredient in most acaricides used for dust mites is benzyl benzoate which has the effect of killing most active mites and the benefit of a residual action, the effect of which is to destroy hatchlings some time after application. Unfortunately, after time the active ingredient becomes inactive, and the object reinfested with mites (de Boer, 1998).

Extremes of temperature can also be used to kill mites. Freezing mites in mattresses with the use of liquid nitrogen and placing children's stuffed toys in the freezer kills mites. Washing bedding and clothing in temperatures above 55°C is effective in killing mites and is a common recommendation. Mites can be killed in carpet by steam cleaning and by placing carpets in the sun (de Boer, 1998).

Unfortunately, while there are several methods available to destroy mites, the offending allergens may well remain behind. The allergens that remain may persist for months or even years in the remaining allergen reservoirs (Strachan, 1998).

Carpet and Mite Interaction

Arlian (1989) reports that "long, or loose-pile carpeted floors harbor significantly more mites than tile or wood floors. Likewise, short, tight-pile carpets, such as those of the indoor-outdoor type, also harbor significantly fewer mites than long, loose-pile carpet, but the former do not support significantly more mites than wood and tile floors" (p. 342). He concludes that removing carpeting from homes would reduce mite exposure in flooring and use of "short, tight-pile carpets" would also reduce mite exposure. In summarizing other research findings, he also concludes there is no correlation between factors such as age of the house, age of the mattress, age of the carpet after the first 6 months, and the presence or absence of pets with higher mite levels and house-cleaning practices (Arlian, 1989).

Lewis and others (1998) studied 26 types of carpet to determine which carpet characteristics contributed to the retention of dust mite allergen. The carpets were different with regard to size and shape of the carpet fiber, the presence of fluorocarbon treatments, and the style, pile height, and density of the carpet pile. Carpet dust was spread over the carpet pieces and embedded using a mechanical device and then the carpets were vacuumed. The findings for recovery of dust and allergen were not always consistent but generally, carpets that are easiest to clean and remove allergens from should have the following characteristics, in order of importance: low pile height and density, fluorocarbon coated fibers, square-hollow shaped fibers, and high denier filaments. It is important to note that all fibers in carpets studied were synthetic and mites were not grown in the carpet.

In a study that attempts to identify carpet characteristics that affect the retention of cat allergen on tufted carpet, Lewis and Breysse (2000) embedded 126 carpet samples exemplifying different characteristics with dust and cat allergen. Characteristics studied were carpet style (cut-pile or loop construction), fiber denier and shape (trilobal or square-hollow), and Teflon™ (fluorocarbon) coating. Carpet samples were vacuumed in an attempt to determine which carpet types yielded the most dust and allergen. Findings of the study, indicated that carpet characteristics affecting retention of cat allergen were, in order of importance: low pile density, low pile height, fluorocarbon fiber finishes, high denier fibers, and use of low surface area fibers such as the square-hollow fiber shape. Carpets having these characteristics were easier to clean and retained fewer allergens (Lewis & Breysse, 2000).

A significant amount of research regarding carpets and dust mites has been carried out but very little attention has been paid to the variables that could exist within the carpet by the researchers. If there is a significant difference in the ability of different carpets to support the growth of dust mites, this research could begin to explain the diversity of research findings.

CHAPTER 4

METHODS

In order to determine if mites would exist in equal numbers in the different flooring environments, the study placed equal numbers of mites in each flooring environment and placed them in a controlled environment for an equal period of time. At the end of the study period, the mites were extracted and counted. This chapter describes the methodology used.

Pilot Study

A pilot study was completed to determine if the full study should be conducted with the carpet samples placed in the Conditioning Lab with or without a carpet pad, and to determine if the study should be conducted over a 4 or 6 weeks period,

Materials

Pieces of residential carpet manufactured using wool, nylon, and polypropylene (olefin) face fibers and polypropylene backing were purchased from a local carpet retailer. Four sets of carpet squares were prepared, two each for the 4- and 6-weeks study period. Each set of carpet squares consisted of a single replicate of each fiber variable and study condition. Therefore, a set consisted of six carpet squares; one wool, one nylon, and one olefin carpet square placed on a carpet pad, and one wool, one nylon, and one olefin carpet square placed directly on the underlayment. Thus, there were four sets of six carpet squares, for a total of 24 samples, in the pilot study.

Twelve 14 cm. x 14 cm. samples, four of each of the three carpet fiber types, wool, nylon, and polypropylene, were cut. Each carpet square was supplied with 0.62 ml. of brewer's yeast in order to assure adequate nutrition for the survival and reproduction of the mites during the period of the pilot study. Yeast was worked into the carpet by hand. All four cut edges of each of the samples were taped with Scotch™ Super Strength Mailing Tape so that approximately 2 cm. of carpet surface on each edge was covered with tape in order to capture and be able to count the numbers of mites attempting to leave each carpet sample microenvironment. The tapes were labeled with identifying information, which included fiber content, date, and 'set' number.

American house dust mites, *Dermatophagiodes farinae,* were obtained from an existing, established colony. Adult female and male mites were removed, randomly, from the colony. Fifty-five mites (50 adult females and five males) were placed on each carpet square using a small, camel hair brush. Carpets were inoculated in groups of six and kept in environmentally controlled, sealed boxes until all 12 samples of the first two sets could be placed in the Conditioning Lab together for the 4-week trial. One week later this procedure was repeated with the second two sets to begin the 6-week trial.

A modular plastic-shelving unit (Contico) with five ventilated shelves was used to house the carpet samples in the Conditioning Lab at Virginia Tech for the study. Each shelf of the shelving unit in the Conditioning Lab was covered with a piece of 23/32" oriented strand board, similar to the type of underlayment that would be used under a carpet in a residential installation. Half of the width of the underlayment was covered with a six pound, rebonded polyurethane residential carpet pad. Twelve of the carpet samples were placed on the same shelf. Half of the samples (two each of all of the three carpet fiber types) were placed on the pad and the other half were placed directly on the underlayment. A large piece of nylon window screening material was placed around the shelving unit to prevent tampering with the samples.

<u>Procedures</u>

At the end of 4 weeks, the first group of carpet samples were removed in the same order in which they were placed in the Conditioning Lab. The method of mite extraction used is a modification of the method described by Bischoff (1992). The transparent side-tapes were removed from each of the carpet squares and affixed to a 4-square per inch graph paper (Quadrille Paper, Dennison Stationary Products Co., Framingham, MA 01710), or equivalent. The process of attaching the transparent tape with mites attached to graph paper allows for efficient counting of mites and labeling of tapes. Each graph paper with its transparent tapes was labeled to correspond to the carpet square from which the tapes were removed to allow for appropriate record keeping. The numbers of mites caught in the side-tapes of each carpet square was counted and recorded.

Side-tapes were again applied to each carpet square in addition to transparent tapes applied to the entire top of each square. After each carpet square had all sides and the top covered with transparent tape, they were placed in the center of a Thremodyne type 1900 hot plate. A 4-pound weight was placed on top of each of the carpet squares to assure that the carpet maintained contact with the heat plate and that the tape remained in contact with carpet. A temperature probe was taped to the side of the center hot plate in each group and connected to the temperature-modulating machine. Each group of three heat plates was connected to a Glas-Col Digitrol II temperature-modulating machine, which gradually increased the temperature from room temperature to 82° C. A temperature of 82° C at the side of the hot plate should yield a temperature in the center of the plate that is at least 90° C.

When the temperature regulator indicated that the target temperature had been reached, the carpet squares were removed and a thermometer was placed in the center of each heat plate to make sure that the temperature had reached 90° C. The top- and side-tapes were removed from each carpet square and placed on graph paper, just as was done with the previous side-tapes. The numbers of mites on the top- and side-tapes were counted and recorded.

When the carpet squares were removed from the heat plates following the heat extraction, the researchers observed that the amount of condensation accumulated on the top-tapes of different carpet squares varied widely, according to the fiber type. The top tapes removed from the wool carpet squares had the greatest amount of condensation, followed by the nylon carpet squares, and the olefin squares had the least. The presence of large amounts of condensation on the top tapes raised the question of whether the mites would be able to stick to the tape when they emerged from the carpet pile during the heat extraction. Therefore, the carpet samples from the 6-week group were also washed to discover mites that were not affixed to the tapes after heat extraction.

Wash Procedure

In an attempt to determine the total numbers of mites in each carpet square after the heat extraction, the 6-week carpet samples were washed and the numbers of mites collected in the second extraction were also counted. Each of the second set of carpet squares was placed, separately, in a plastic dishpan (Rubbermaid, item # 2951). Liquid dish washing detergent was placed on the carpet square and put into solution using the sink aerator and hot tap water. After the detergent was in solution, the carpet square was scrubbed using the investigators' fingertips and the square was manipulated to dislodge mites.

After scrubbing, individual carpet squares were removed from the wash-pan and placed over a set of U.S.A. Standard Testing Sieves (top sieve: ASTME-11 specification No. 35, Tyler Equivalent Mesh 32, opening of 500 micrometer / 0.0197 inches by Fisher Scientific Co.; bottom sieve: ASTME-11 specification No. 35, Tyler Equivalent Mesh 200, opening of 75 micrometers / 0.0029 inches by Fisher Scientific Co.) for rinsing. Using the sink aerator, each carpet square was washed with tap water that was drained into and filtered by the pair of sieves. The water from the dishpan was also poured into the set of sieves and the dishpan was rinsed with tap water from the sink aerator. The debris trapped in the larger, top sieve was discarded. The material in the smaller, bottom sieve was thoroughly rinsed and then washed into a Büchner funnel (Coors, C-46) fitted with a Whatman (9.0 cm., # 42) filter paper in the bottom to catch the mites for counting. Using a vacuum pump, the excess water was evacuated into a filtering flask (KIMAX 500 ml.) and discarded. The filter paper containing the mites was removed from the funnel and counted under the microscope.

The numbers of mites on the side-tapes for each carpet square were counted under a microscope and recorded. The numbers of mites adhering to the side-tapes and top-tapes used during the heat extraction were counted and recorded in the same manner. Though the number of mites found after scrubbing was available only for the second set of carpet samples, the 6-week set, these numbers were also recorded.

Results of Pilot Study

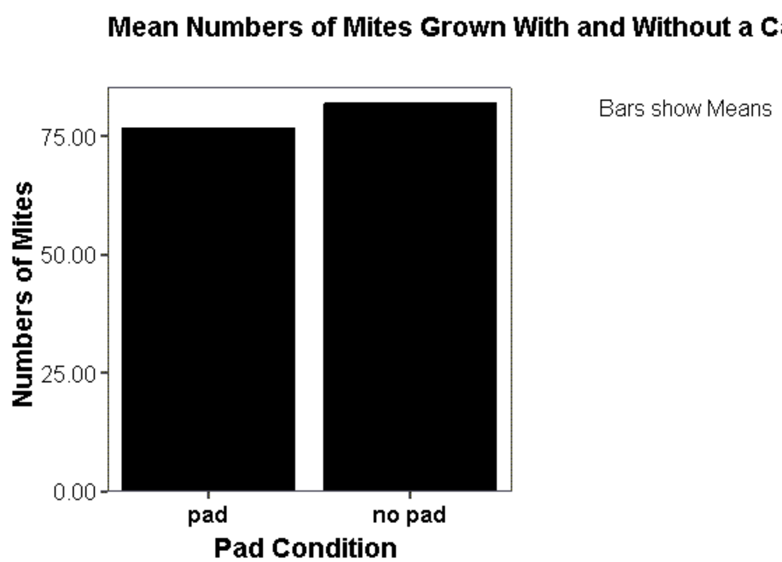
All statistical analysis were conducted using SPSS® Graduate Pack 9.0 for Windows computer software package.

Carpet Pad Versus No Carpet Pad

The first purpose for conducting the pilot study was to determine whether it was advantageous to conduct the study with the carpet pieces on a carpet pad or not. In order to determine if there was a significant difference in the mean numbers of mites in carpets with or without a pad, an independent samples t-test was conducted. Based on the results of Levene's test for equality of variances, homogeneity of variances was assumed. At an alpha level of .05, the differences between the numbers of mites grown in carpet with and without a carpet pad were not significant ($p = .777$). Figure 2 depicts the mean numbers of mites grown in carpet squares placed on a carpet pad and those grown on carpet squares placed directly on the underlayment.

Figure 2.

Mean Numbers of Mites Grown With and Without Carpet Pad



4-Weeks Versus 6-Weeks

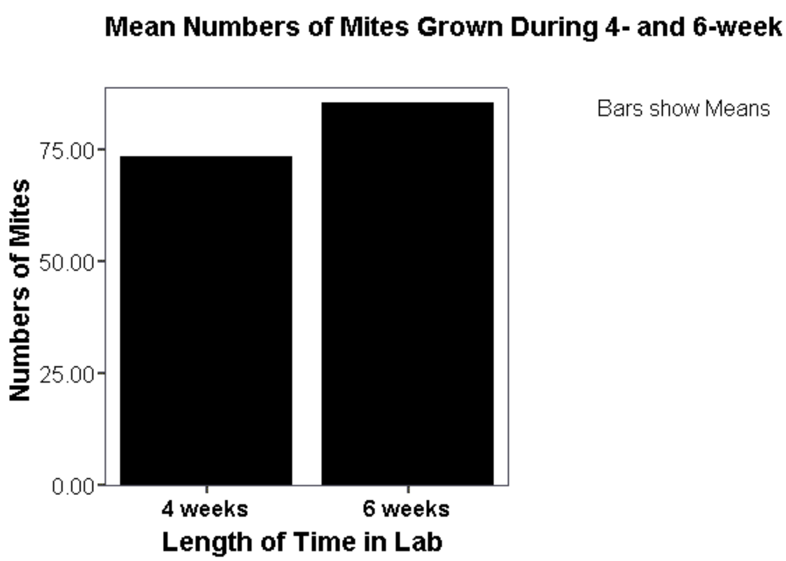
The second purpose for conducting the pilot study was to determine if mite-infested carpet squares should be kept in the Conditioning Lab for a 4-week or a 6-week period.

A t-test was conducted to determine if there was a significant difference between the means for the 4- and 6-week study periods. Levene's statistic indicated that the assumption of homogeneity of variances had been met. The difference between the four groups of samples was not significant ($p = .513$) at an alpha level of .05. There were, however, a greater number of mites grown in the set of carpets kept in the Conditioning

Lab for a 6-week period, as shown in Figure 3. The results of 'washing' the carpet samples were not included.

Figure 3.

Mean Numbers of Mites Grown During Four- and Six Week Periods



<u>Discussion of the Pilot Study</u>

While the difference in mean numbers of mites grown in carpet squares with a pad or without a pad were not significantly different, the total numbers of mites recovered from the carpet square without a pad were higher (984), when compared to the numbers of mites recovered from carpets over a pad (921). It was decided, therefore, not to use a carpet pad under the samples in the full study. This decision had the advantage of not introducing an additional variable into the study.

The same logic was applied to the decision of whether to keep samples in the Conditioning Lab for 4- or 6-weeks. While there was no significant differences in the mean numbers of mites grown during the 4- and 6-week periods, there was a greater number of mites retrieved from carpet samples grown during the 6-week period. It was decided to leave the carpet squares in the Conditioning Lab for a 6-week period for the full study.

There were several concerns regarding the method used to extract mites from the carpet squares. The first concern was the large amount of water that collected on the top-tapes of the wool carpet samples during the heat extraction process. There was no way to determine if the water prevented the mites from reaching the tapes or prevented them from sticking to the tapes if they did reach them.

A second concern was the number of mites discovered to be in the carpet squares that were scrubbed. In several cases, the numbers of mites recovered by scrubbing after the heat extraction was equal to or greater than the number recovered previously in the heat extraction. While the mites recovered by scrubbing were quite possibly dead at the time of heat extraction, they had lived for an undetermined amount of time in the carpet. In retrospect, there was no way to determine if any of the mites had been moved to the carpet from the colony culture or if they had emerged from an egg laid in the carpet after the initial infestation. It is also impossible to determine the age of adult mites being removed from the culture at the time of the initial infestation and, therefore, the natural life expectancy of the mites being selected for removal to the carpet square. Consequently, the decision was made to remove and count all mites in the carpet squares using the scrubbing method previously described, instead of simply the living mites using the heat extraction method.

To briefly summarize, as a result of the pilot study, it was decided that the study would be conducted without a carpet pad under the carpet samples and over a 6-week period. It was also determined that the numbers of mites grown in the carpet flooring samples over the study period would be determined by washing the samples.

The Research Study

This study was conducted to determine if there was a difference in the numbers of mites grown in carpet samples with different carpet characteristics, specifically differences in carpet fibers, and to compare those differences with a control flooring sample. The control sample is hard flooring.

Methods

In order to determine an appropriate statistical sample size, a power table was consulted (Gall, Borg, & Gall, 1996). The analysis of variance table for four study groups was used. Since no similar studies have been carried out to determine if there was a difference in numbers of mites grown in different carpets, a medium effect size and alpha = .10 were chosen arbitrarily. On the basis of findings in the power table, the study consisted of 18 replicates of 4 flooring materials each, for a total of 72 flooring samples.

Each sample was 14 cm. x 14 cm. in size. The flooring materials used were 3 commercially available, residential carpets, one constructed of wool, one of nylon, and one of polypropylene (olefin) carpet fibers, and one hard flooring material, a commercially available laminated strip flooring material. Some of the carpet characteristics of the carpets used in the research study are described in Table 1.

The structure of the laminate strip flooring material consists of an exterior laminate surface material consisting of a clear protective wear layer covering a layer containing the image of the hardwood being simulated. These layers cover a core of high density fiberboard and a laminate backing material, which adds strength and stability. Individual boards can be joined together by a tongue-and-groove bonding system (Armstrong Laminate Flooring, 2000).

Table 1

Research Study Carpet Characteristics

	Wool	**Nylon**	**Polypropylene**
Fabric type	Textured loop	Cut / uncut	Berber pattern loop
Pile yarn content	100% Wool	100% BCF Nylon	100% Olefin
Yarn – twists per inch	1.75 x 1.50	4.50 x 4.50	Air entangled
Pile height	.375	.344	.406
Finished pile thickness	.350	.300	.320
Stitches per inch	4.6	12.6	8.7
Labeled face weight	42.2 oz/yd^2	39.0 oz/yd^2	41.0 oz/yd^2
Density	4361 oz/yd^3	4680 oz/yd^3	4613 oz/yd^3
Primary backing	Polypropylene	Polypropylene	Polypropylene
Secondary backing	Polypropylene	Polypropylene	softbac

As in the pilot study, each flooring sample had all four sides taped with Scotch™ Super Strength Mailing Tape covering approximately 2 cm. of the edges of the flooring material. Each sample was labeled with the date and the 'set' number of which it was a part. No attempt was made to identify the fiber content of the carpet samples at this time and carpets were simply labeled 'A', 'B' and 'C'. The laminate floor was labeled 'D'. Additionally, each flooring square had 0.62 ml. of brewer's yeast applied to the top. In the case of the carpet samples, the yeast was worked into the carpet by hand. On the hard floor, the yeast was spread evenly on the surface of the sample by hand.

Each flooring material sample was infested with 50 adult female and five male house dust mites, *Dermatophagiodes farinae.* The mites were selected randomly from an existing, established colony using a camel hair brush. Flooring materials were inoculated in sets of four (one of each fiber type plus one control) staggered over a 7-day period. Each days' sets of samples was kept in a sealed box until all infested samples could be placed in the Conditioning Lab together, at the end of the day.

A modular, plastic shelving unit (Contico) with five ventilated shelves with a 23/32" oriented strand board underlayment on each shelf was used to house the samples in the Conditioning Lab at Virginia Tech. All samples were placed directly on the underlayment. Sets were kept together and placed so that 'like materials' were never side-by-side on the shelves.

The temperature and relative humidity in the Conditioning Lab were measured 12 times during the course of the study. The temperature in the Conditioning Lab ranged from 70º to 85º, with a median temperature of 77º. During the same period the relative humidity varied from 30% to 60%, and the median relative humidity was 55%. Some of the variablity in temperature and relative humidity was probably due to opening and closing of the doors to the lab and the fact that adjoining rooms, while heated and air-conditioned, were not maintained at the same condition as the lab.

At the end of the 6-week study period, samples were removed in the same order in which they were placed in the Conditioning Lab. The side tapes were removed and placed on a 4-square per inch graph paper (Quadrille Paper, Dennison Stationary Products Co., Framingham, MA 01710), or equivalent. Each graph paper was labeled with the identifying information from the individual flooring sample and the numbers of mites in the side tapes were counted and recorded.

Following removal of the side tapes, the carpet samples were placed in a dishpan (Rubbermaid, item #2951) and had dishwashing detergent applied to the surface. The detergent was put into solution using the sink aerator and very warm tap water. The carpet pile of each square was scrubbed with a metal instrument and the square was repeatedly manipulated and bent in order to dislodge the mites.

After scrubbing, each carpet square was taken out of the dishpan and rinsed, front and back, with tap water from the sink aerator over a set of U.S.A. Standard Testing Sieves (top sieve: ASTME-11 specification No. 35, Tyler Equivalent Mesh 32, opening of 500 micrometer / 0.0197 inches by Fisher Scientific Co.; bottom sieve: ASTME-11 specification No. 35, Tyler Equivalent Mesh 200, opening of 75 micrometers / 0.0029 inches by Fisher Scientific Co.). The contents of the dishpan were also poured through the set of sieves and the dishpan was rinsed into the sieves with tap water from the sink aerator.

The hard flooring sample was placed directly into the larger top strainer and wetted with tap water and dishwashing detergent. The surface of the flooring material was rubbed with fingertips to dislodge all mites and yeast and then all surfaces of the square were rinsed with tap water.

Material in the top strainer was discarded. After thoroughly rinsing, the contents of the finer, bottom filter was washed into a Büchner funnel (Coors, C-46) fitted with a Whatman (9.0 cm., # 42) filter paper in the bottom. The water in the funnel was pumped, using a vacuum pump, into a filtering flask (KIMAX 500 ml.). After the filter paper was removed from the funnel, it was placed under a microscope and the numbers of mites were counted. A professional entomologist carried out all counting of mites, from both side tapes and filters.

CHAPTER 5

RESULTS

All statistical analysis were conducted using SPSS® Graduate Pack 9.0 for Windows computer software package.

In order to test the hypothesis:

$$H_O : C_W = C_N = C_P$$

and the alternate hypothesis:

$$H_1 : C_W \neq C_N \neq C_P$$

analysis of variances were conducted to compare the means of the numbers of mites grown in each of the three types of carpet fibers (wool, nylon, and polypropylene). All tests were conducted at the 0.01 level of significance.

Assumptions About Data

Prior to determining the analysis of variance, the data was examined to determine if the assumptions had been met.

- The first assumption, independence of observations, was assumed to have been met.
- The second assumption, normality of distribution, was tested using histograms for the three dependent variables, numbers of mites from side tapes, numbers of mites from washing, and the total number of mites. The three histograms were positively skewed, indicating a greater number of smaller values. Since the histograms were not highly skewed, the assumption was assumed to have been met.
- The third assumption, homogeneity of variances, was tested using Levene's statistic. Because Levene's statistical test for the homogeneity of variances was found to be significant (p=.000), this assumption was not met. This was not considered to be problematic since two variables (side-tapes and washed) were measures taken directly from individual samples and the third variable (total) was a sum of the two direct measures.

The three dependent variables were also highly correlated, as seen in Table 2.

Table 2

Pearson Product Moment Correlations

	Side-tapes	**Washed**	**Total numbers of mites**
Side-tape	1.000		
Washed	.690	1.000	
Total numbers of mites	.749	.762	1.000

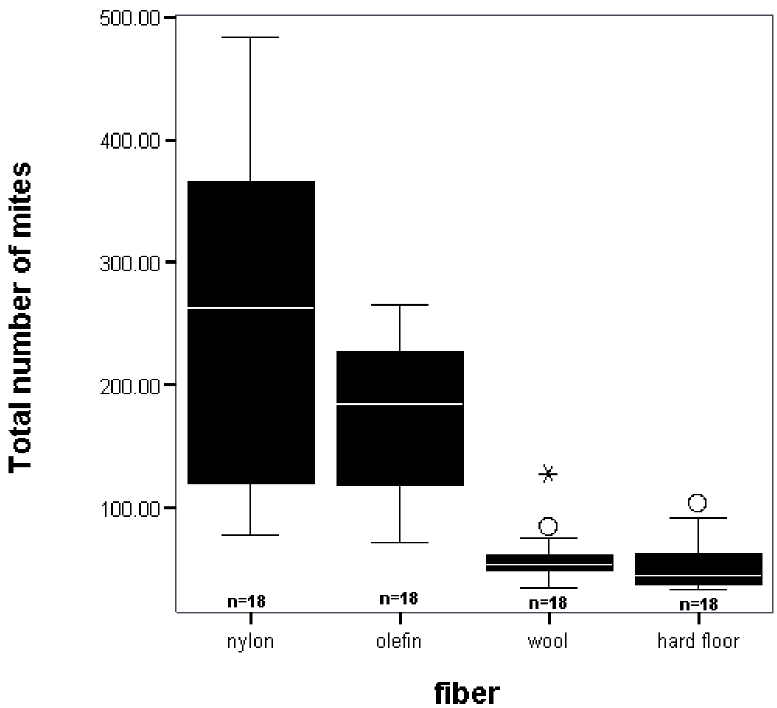
In order to determine if there were any outliers, boxplots were created for each of the flooring materials. Boxplots revealed two outliers, and one extreme value. All of the outliers and extreme values were higher than other values and existed only for the wool carpet and the hard floor. When statistical studies were conducted with and without the outliers and extreme value no remarkable differences were observed and statistical differences were unchanged. Therefore, all statistical studies were conducted with the outliers and the extreme value in the data. The boxplots are shown in Figure 4.

The mean numbers of mites grown in each of the different flooring types is described in Table 3. When ranked from highest numbers of mites counted per flooring material to lowest, the juxtaposition reveals the placement of the wool fiber carpet, the material with the highest moisture regain, between the two materials with the lowest moisture regain, the olefin carpet and the hard floor.

In order to test the null hypothesis and to determine if there was a statistically significant difference between the mean numbers of mites grown in carpets constructed using different carpet fibers and the mean numbers of mites grown on a hardwood floor analysis of variance statistical studies were conducted. The four flooring types were the independent variable and the dependent variable was the numbers of mites grown in each micro-environment. The level of significance was set at 0.01. Results of the ANOVA ($F = 33.604$, $p = .000$) revealed that a significant difference existed among the four flooring types.

Figure 4

Boxplots



In order to determine which groups differed and to organize the four flooring types into homogeneous subsets, Duncan's Multiple Range Test was conducted using the total numbers of mites as the dependent variable. Table 3 indicates the groupings that resulted from this test. In reporting the results of Duncan's Multiple Range Test, different letters are used to represent statistically comparable groups. Results indicate three statistically significantly different groups of flooring types. One group contains nylon, with the highest numbers of mites. Another group contains olefin, with the second highest numbers of mites grown in that sample. The last group contains both the wool fibers and the hard floor, both with the fewest numbers of mites grown in these samples and statistically similar means.

Table 3

Mean Numbers of Mites

Flooring Type	N	Mean	Standard Deviation	Minimum	Maximum
Nylon	18	255.44 a	126.99	78.00	484.00
Olefin	18	176.61 b	61.26	71.00	265.00
Wool	18	58.06 c	21.60	35.00	129.00
Hard floor	18	51.78 c	20.58	33.00	105.00

$F = 33.604$, $p = .000$
a, b, & c represent homogenous groupings using Duncan's Multiple Range Test (subset for alpha = .01)

On the basis of the results of statistical tests run on the study data, the null hypothesis that there is no difference between the numbers of mites grown on the different flooring conditions, was rejected. When comparing the control group, the hard floor, to the three residential carpet samples, there was a significant difference between all groups except the wool carpet and the hard floor, which had statistically similar means.

Since mites are completely dependent on the relative humidity of their environment for their survival, one might reasonably expect their numbers to be related to the environment in which they existed according to moisture content. This is not the case. Mites existed in highest numbers in the carpets assumed to have moderate and low moisture regain. Oddly, they existed in lowest numbers on the hard floor and the carpet understood to have the highest moisture regain, and there was no significant difference in the mean numbers of mites in those opposite conditions.

CHAPTER 6

SUMMARY

The incidence of allergy and asthma in increasing both in the United States and worldwide. House-dust mites are endemic and are a source of a powerful allergen to which people frequently respond. Mites exist in large numbers in many carpets and, for this reason, healthcare professionals frequently recommend the removal of carpets from the homes of persons with allergies.

Research exists describing the effect on human beings of having large numbers of house-dust mites in their immediate environment, conditions in the larger environment that allow mites to exist in interiors, the difficulty of killing or removing mites and their allergens from carpets, as well as comparisons of numbers of mites in carpeted and non-carpeted floors. In the allergen and mite research literature, carpets are rarely described as having unique characteristics and are generally referred to as a generic entity. The characteristics of carpets that might effect the growth of mites within the carpet microenvironment have not been addressed. Carpets, however, do have unique characteristics that define their construction, appearance, wearability, and cleanibility.

Carpet fibers differ in their ability to absorb moisture. Wool has a rate of moisture regain of 13-18%; nylon has a moisture regain rate of 4.5%; and olefin a rate of less than 1%. While mites exist in an environment in which there is not water in the liquid phase, the single greatest determinant of whether mites can exist in an environment is the relative humidity of that environment. Is it reasonable to assume that carpets constructed of fibers that retain more moisture provide a more supportive environment for the existence of mites?

The purpose of this study, therefore, was to determine if, under identical, controlled environmental conditions, mites will exist in equal numbers in similarly constructed carpets designed with different fibers.

In order to determine if mites would grow in greater numbers in one carpet than in another, and if they did exist in fewer numbers on hard flooring, 72 flooring samples were studied over a 6-week period. Each sample was inoculated with 50 adult female and five male mites of the species *Dermatophagiodes farinae*. All samples were placed in a Conditioning Lab and maintained under identical conditions. At the end of the 6-week period, samples were removed from the controlled lab in the same order in which they were placed and the numbers of mites from each sample were counted.

The results of this study demonstrate that there is a significant difference in the numbers of mites growing in different flooring microenvironments. The difference between the mean numbers of mites grown on nylon and wool, and also on olefin and wool carpet samples were significantly different (p <.01). The numbers of mites grown on hard floor and nylon, and on hard floor and olefin were significantly different. Many more mites were able to exist in the nylon carpet and in the olefin carpet than on the hard floor. The differences in mean numbers of mites grown on hard floor samples and those grown on wool carpet samples were not significantly different. These two environments, the hard floor and the wool carpet, were the least supportive of mites.

Discussion

Hard floors have been promoted as the best flooring alternative for persons with allergies. This appears, on the basis of this study, to be a justifiable recommendation. Hard floor had the fewest numbers of mites at the end of the test period and this number was significantly different from two carpet fiber types, nylon and olefin. What is surprising is that one of the fiber groups, wool, differed little in comparison to hard floor in mite growth. House dust mites are completely dependent on high relative humidity for their survival. When viewed in this context, the finding that mites survive in comparable numbers in a flooring material assumed to have almost no moisture regain and the study material with the highest expected moisture regain is completely unanticipated.

One possible explanation for this odd finding is that the wool carpet may have been treated with an insecticide, permethrin, as part of it's finishing. Moth-proofing of wool fibers is a common practice in the textile industry and permethrin is a common moth-proofing agent (K. Sellers, personal communication, October 2, 2000). In addition to being an effective agent against moths, permethrin is also prescribed for human use in cases of mite and nit infestation, such as head-lice and scabies. It is logical then that if permethrin were used on carpet fibers it would inhibit the growth of mites in carpets constructed of that fiber. All of the carpet samples in this study were new and had never been placed in a home. It would be interesting to know if the permethrin finish is deteriorated in the process of routine carpet cleaning and vacuuming or gradually looses it's apparent ability to deter the presence of mites over time.

Carpet constructed with nylon fibers had the highest numbers of mites grown. Among the three tested fibers, nylon fibers have the next highest expected rate of moisture regain and no indication of insecticidal treatments or biological growth preventative. Nylon is the most commonly used fiber in residential carpet construction. While nylon carpet is not consumed by insects and would therefore, not logically receive an insecticidal treatment, would such a treatment be equally effective in deterring mite growth in carpets constructed with this fiber? It would also be interesting to know if antimicrobial treatments affect the growth of mites in carpets.

It should also be noted that wool is the most expensive carpet fiber. The less expensive fibers grew more mites than wool carpet. Could this be related in any way to the increased incidence of allergy and asthma in groups that are often less well-off financially?

Previous studies have treated carpet as a generic entity. Some have shown differences in numbers of mites on hard floor and in carpet and some have not. This study could explain what appears to be an inconsistency in previous findings. If those studies were done using wool carpet similar to that used in this study there would likely be no difference in the two types of flooring. However, if a study was done using nylon carpet, the difference in mite growth in the two flooring types could be dramatic.

Conclusions and Recommendations

This study shows clearly that carpet is not a generic entity. There are significant differences in the growth of house dust mites in carpets of different construction characteristics, in this case carpet fibers. The reasons for the differences are unclear and unexpected. The carpet environment which could reasonably be expected to be the most supportive of mites, the carpet constructed of wool fibers, is statistically similar to a hard floor. It is possible that this difference is due to the fact that many domestic and imported carpets and rugs are treated with permethrin to deter carpet moths and beetles. This is a possibility that needs to be investigated further.

More research needs to be done to determine what other carpet construction characteristics, such as pile height and pile density, affect the growth of mites, and other organisms, in carpets. This study establishes that fiber can make a difference in the environment for the growth of mites in similarly constructed carpets. However, more work should be done to determine how the interaction of different construction characteristics affects the growth of mites and other organisms in carpets. By controlling more variables in future studies it may be possible to isolate individual variables associated with higher mite growth rates.

The nature and structure of the carpet fibers themselves should also be investigated. Does the unique three-dimensional crimp of the wool fiber make mites more difficult to remove from a wool carpet?

The interaction of carpet and other variables not directly related to the carpet itself should also be studied. For example, were there fewer mites in the carpets placed on the carpet pad in the pilot study because the mites left the carpet itself and moved into the pad? Are some types of carpet pad more supportive of mite growth than others?

There are valid reasons to use carpets and rugs in homes. It seems possible, once we establish which carpet characteristics are most and least supportive of the growth of mites and other organisms, to design carpets with characteristics that allow people to have carpets in their home and not increase their risk of exacerbating allergic or asthmatic conditions.

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