The Science of Carpet Cleaning

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ABSTRACT

Cleaning as a process is well defined by IICRC S100, as are the steps involved in industry-accepted methods of carpet cleaning. Indoor Environmental Quality (IEQ) problems, related to maintenance and cleaning must be viewed holistically. Currently, diverse cleaning applications appear unconnected. Commercial and institutional building maintenance issues are disconnected and seldom are daily housekeeping, periodic maintenance and restorative cleaning programs coordinated. Proper maintenance and cleaning, employed proactively in a well planned and managed built environment, can prevent or solve most problems related to IEQ issues. Much if not most of the current body of science related to carpet cleaning appears to concentrate on somewhat narrow, quantifiable issues, rather than the overall result of the cleaning process. While there are several excellent studies on the types and quantities of soil in carpet, soiling methods are deficient in that they fail to reproduce the conditions that cleaners encounter normally in the field. The body of science related to cleaning is not broadly published and disseminated to the individuals who need the information.

INTRODUCTION

For the purposes of this paper, a literature review has been conducted on the science of carpet cleaning. Literature searches accomplished during the 1960-80's reviewed studies dating to the '70s and '80s. This research on cleaning chemicals, carpet soils and other quantifiable topics still has relevance today. However, the research on cleaning methodology is noticeably lacking.

The science of cleaning involves the evaluation of the carpet (fiber, construction, color, age, traffic patterns and soiling conditions) and cleaning (chemistry, temperature, pre-conditioning, water flow, speed of tool movement, and number of repetitions). Scientific maintenance and cleaning of carpet involves planning, management, procedural requirements, and highly specialized chemicals and equipment. Moreover, as building owners and managers look at the cost of failing to maintain and clean their buildings, they have begun to recognize not only the depreciation associated with failures in this area, but also the real health compromises and costs. Beyond the accelerated depreciation of assets, the costs that are the most difficult to quantify, such as lost productivity and absenteeism, relate directly to compromised maintenance and cleaning.

Carpet is only one part of the whole complex subject of indoor environmental quality. Every residential and commercial building must be viewed holistically in defining IEQ concerns and solutions.

Carpet Soil

Most carpet wears out or devolves to an unacceptable appearance long before it should, for three reasons: 1) little effort is made to keep soil out of the carpet; 2) little effort is made to get newly deposited soil out of the carpet on a routine basis with in-house maintenance procedures; 3) owners fail to apply cleaning procedures regularly.

Before carpet soiling can be corrected, the source of the soil as well as its composition must be determined. Some terminology is in order.

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[a] Clean Care Seminars, Inc. and Institute of Inspection, Cleaning and Restoration Certification.
[b] Prepared August 2003.

Carpet soil - any unwanted substance deposited on, or within carpet, as the result of wear and usage, e.g., particles, foreign fibers, or water-soluble or dry solvent-soluble substances (food, oils, greases, etc.).

Arresting Soil - keeping soil out of carpet is a preventative step achieved by maintaining exterior walkways and using entry mats inside and outside the building. Destructive soils accumulate within the first five to six feet of entry areas in residences. In institutional or commercial buildings, soil may progress much farther inward if it isn't controlled at the entry. If soil is arrested at entryways with proper exterior maintenance and barrier matting systems of sufficient size, the whole building stays cleaner and less time is spent maintaining floors, furnishings and fixtures. However, entry mats must be vacuumed, shaken and flushed free of abrasive soil periodically in order for them to perform efficiently.

Sources and Types of Carpet Soil

There are basically two sources of soiling, and the soils that come from these sources are placed into three distinct classes or types. Further, these soils accumulate on three different levels within the pile. From the outside, tracked particles (e.g., sand, clay, grass, leaves, and fibers) enter homes or businesses, along with airborne pollutants from industrial and automotive exhaust emissions. Geography influences the composition of soil. Inside the home or business, soiling comes from shed dander and hair (animal and human), shed fibers of fabrics and paper goods, body oils and food substances, or from commercial work processing (like toner and copy machine particulates). Probably the least recognized, but most significant source of problem soil that builds on fiber comes from animal and vegetable oils that are generated in food service areas or kitchens.

Types of Soil

For cleaning to be effective, the physical and chemical properties of soil types must be understood.

- **Water-soluble** soils include materials that dissolve easily in water, such as sugar, starches, salts and other fluidic residues.

- **Dry solvent-soluble** soils include asphalt, tar, grease, and animal or vegetable oils that are produced when cooking food. Oily soils also accumulate on carpet just inside entries from specialized work areas or parking lots (particularly asphalt or top coated areas). To compound the problem, if oily soils are allowed to remain in the carpet too long without being removed, they may dry out or "oxidize." When this occurs, a hard, yellow, lacquer-like film is formed which requires additional time and aggressive chemicals for removal. Some oleophilic (oil loving) fibers (polyester, olefin) may actually absorb oily soils over time, leaving a yellowish cast to traffic areas that cannot be removed with cleaning. With proper pre-treatment and maximum application of the principles of cleaning, oxidized oils may be removed almost as easily as other types of soil.

- **Insoluble** soil includes particles, such as clay, sand (disintegrated rock particles), quartz (mineral composed of silica), feldspar (silicate of aluminum combined with other elements), limestone (calcium carbonate), gypsum (plaster of Paris) and carbon. Insoluble soil also includes cellulosic fiber from clothing, paper products, grass and leaf fragments, and protein fibers shed by human beings, pets and clothing. Dermatologists estimate that average adults shed over 300 hairs per day from various parts of their bodies along with some 300,000 skin cells. Much of this soil winds up on the horizontal surfaces in the home or business, including the carpet. All these soils are classified as insoluble in the sense that they cannot be dissolved with chemicals used in normal cleaning. Therefore, they must be removed in some other manner; otherwise, they remain in carpet even after cleaning as a form of soil

Soil Buildup

Soiling, particularly of particle soils, tends to collect in entry areas first. As entry areas become saturated, particle soil is deposited further into the inner areas of the building. Eventually, traffic areas across an entire room may become loaded with quantities of abrasive sand and grit, which causes an adverse effect on thermoplastic carpet fibers. Therefore, it is important to arrest particle soils with entry maintenance and barrier matting and to remove soil from these areas regularly to prevent damage to any floor covering.

Soil builds on three distinct levels within the carpet's pile. Hair, cellulose, and light or sticky soils, such as dust, gummy sugars, or oily soils remain at the surface. The middle third of the pile contains heavier particles of dust, fiber and vegetable matter. The lower third, near the primary backing, contains the heaviest and most destructive soil particles, such as sand and grit.

Soil Analysis

According to popularly cited studies (Proctor and Gamble Laboratories, DuPont) that analyze carpet soil samples from throughout the continental United States, 55% of this "average" soil sample consists of the abrasive particles: sand, quartz, clay, limestone, gypsum and carbon. Approximately 10-12% of this soil sample consists of human or animal dander and hair. Another 12-14% consisted of vegetable (cellulosic) fiber.

From 74-79% of the carpet soil sample is dry particle soil, which conceivably could be removed with dry vacuuming. Sticky or oily soils bind to fibers and are not removed with dry vacuuming. Also, a significant portion of dry particle soil is bound to fibers by sticky or oily substances that are not removed with dry vacuuming.

Only 16-22% actually requires chemical cleaning to dissolve soils before removal can be accomplished. However, when quantities of these oily, sticky residues accumulate, they serve as binders for a portion of the abrasive particle soil present. Also, fine particles of carbon and dust may be bound to thermoplastic fibers by electrostatic forces inherent in the fiber's molecular structure (van der Waals forces - the relatively weak forces of attraction existing between atoms or molecules, caused by the interaction of varying dipoles). These soils are not removed with dry vacuuming, and they may present a challenge even for aggressive chemical agents.

Carpet Soil Summary Chart

Type	Composition	Source	Res. %	Com. %
Insoluble Particles or fibers	Clay, sand, quartz, carbon feldspar, gypsum	Tracked from exterior	55%	50%
	Protein fiber	People, pets, fabrics	12%	10%
	Cellulosic matter and fiber	Tracked from exterior (grass, leaf fragments); shed from newspaper, magazines, paper, clothing; interior plants	12%	14%
Subtotal			**79%**	**74%**
Water soluble	Sugar, starch, salts, fluidic residues	Foodstuffs, body fluids	6%	12%
Dry solvent soluble	Tars, asphalt; Animal, vegetable oils	Tracking, cooking vapors, body oil (human, animal)	10%	10%
Moisture	Humidity	Outside air; inside activities	3%	2%
Unknown			2%	2%
Total			**100%**	**100%**

***** Analysis of carpet soiling from samples representing a cross-section from throughout the United States – Sources: Proctor and Gamble Laboratories (residential) and the DuPont Company (commercial).

A literature search accomplished by Dr. Al Luedtke in 1997 summarized the following:

> Several studies on soils from various parts of the world indicate that it is remarkably similar in make up. It is about 60% inorganic salts (silicates, phosphates, etc.), 20% fiber (animal and cellulosic), ca. 15% macromolecular organics (resins, gums, etc.), and about 3-5 % lower molecular weight organics (non-volatile greases, fats, and oils). The particle size of the dusts that tend to be most commonly associated

with fiber surface soiling is in the 2 micron range (NOTE: the fiber surface will appear nearly flat compared to a particle in this size range).

The actual binding of soil to the fiber is attributed to three mechanisms: 1) occlusion in the fiber surface structure and within the fiber bundle, 2) electrostatic forces, and 3) oil binding, in which the particle becomes imbedded in a soft organic matrix. Most researchers agree the oil binding mechanism is the most important in soil accumulation on carpet fibers. Although the first two certainly occur, the forces holding particles to the fiber in these situations can be easily overcome by most routine cleaning. Therefore, the 10-20 % organic fraction of soils is the most problematic in soiling; i.e., it is the source of the soft organic matrix, which ultimately leads to accumulation of visible particles and the degradation in appearance of the carpet.

The initial contact of the soil with the carpet appears to be predominately by foot traffic. Most papers use the breakdown of 80% associated with shoes and 20% airborne. There is no obvious technical basis for this ratio in that the paper most frequently referenced on this point makes the statement without supporting data. Nonetheless, the assertion is not unreasonable. I would point out, however, that it is possible that a larger fraction of the smaller particles (1-10 micron range) may be airborne-sourced.

The other important consideration in regard to soiling is the observation that the fiber appears to "saturate" at some point and will reach equilibrium; i.e., soil will walk in and will also walk out. The saturation or equilibrium is a function of several variables, including fiber shape and oil content of the soil. This was well demonstrated by Rivet in his internal work and is also observed in an exercise by Westenberg in which a heavily soiled carpet was placed between two new samples. In a matter of days the three carpets were very similar in appearance; i.e., the heavily soiled carpet lightened as soil transferred to the cleaner samples.

It is also important to understand the carpet attributes that play significant roles in soil accumulation and in the visual appearance of soil. A fair amount of the literature covers these areas. Not surprisingly, the color and the pattern of the carpet were determined to be critical with regard to the appearance of visible soil. Of course, carpet that is either very light or very dark does not perform well. It was found that medium to medium-dark colors in random patterns hide soil very well. In addition, the delustering properties of the fiber tend to be important, i.e., the inclusion of TiO_2 or PEO in the polymer, and the light refraction properties of the cross section (hollow filament better than trilobal). The overall surface area of the fiber is reported to be important (less is better) in several studies. Finally, the use of a fluorochemical after-treatment is demonstrated in several studies to provide considerable anti-soiling benefits, especially at the early stages of the soiling process, i.e., it significantly delayed visible accumulation.

The theory around soil removal from carpet fibers is based predominantly on wet cleaning work with other textile fabrics. It is not be unreasonable to expect carpet fibers to behave similarly. As indicated earlier, Erik Kissa, writing in "Chemicals," conducted a considerable amount of work in this area. He discusses in some detail the mechanisms around removal of soils. It is noteworthy that the initial steps in the cleaning process, as hypothesized by Kissa, involves displacement of the oils at the fiber/surface interface with surfactants. Subsequent steps are micelle formation and suspension. His discussions make interesting reading.

Methods for the assessment of soiling or soil accumulation have been a key focus in several published studies. Historically, there have been a variety of approaches utilized, and most have been of some value. These range from simple subjective rankings to complex light reflectance techniques. With regard to the latter, early efforts involved use of lightness/darkness measurements; however, experience proved that this approach broke down when evaluating the performance of carpets of significantly different colors. Also, there have been gravimetric methods employed to assess soil accumulation and removal, and DuPont has found that XRF correlates very well with soil accumulation, and hence, visible soiling.

Currently, the two most popular approaches to soiling measurements are application of the AATCC gray scale and the use of ΔE or L_{ab} measurements. The former is pretty simple, but seems to correlate fairly well

with the subjective visual assessment of the observer and the more sophisticated ΔE technique as reported in several studies."

Preventive Maintenance

In addition to entry maintenance and barrier matting, effective use of efficient vacuum cleaning equipment is necessary. Often the importance of routine carpet maintenance is minimized until the carpet is declared uncleanable. The primary responsibility for removing dry particle soil from carpet must lie with end-users. Moreover, it must be accomplished on a routine basis to prevent abrasive soil from sifting downward to the base of yarns where it begins its destructive work. It is unrealistic to expect to remove all of fine particle soils with even the most professional vacuum equipment after the soil has had extended time to accumulate slowly at the base of the pile. When particle soils accumulate to a saturation point in carpet pile, not only do they affect appearance, but they also become very difficult to reduce to acceptable levels without time-consuming vacuuming procedures. If vacuuming isn't programmed at regular intervals, soil accumulation is inevitable.

There are two basic types of vacuum units - canister and upright. The Carpet and Rug Institute's Green Label provides assurance that vacuum cleaners bearing this designation have met reasonable performance testing criteria in the areas of soil removal, dust containment, and carpet appearance retention. Canister vacuums are primarily designed for upholstery, drapery and hard surface floor maintenance. Without an appropriate agitation attachment for carpet, the airflow alone generated by a canister vacuum does little more than remove surface soil from high-density carpet pile. On low, level-loop styles, canister vacuums perform somewhat better. Upright vacuums are designed specifically for brush agitation of the carpet pile for maximum dry soil removal. The upright's brush-bar combs out hair, lint and strings, while it vibrates and lifts particle soil, such as dust, sand and grit into the air stream generated within the vacuum nozzle. Soil is picked up in the vacuum air stream, where it should be deposited in a top-fill, high-efficiency, disposable recovery bag. A top-fill configuration ensures minimally impeded airflow even when the bag is ½ to ⅔ full. Otherwise, once the bag is one-half to two-thirds filled, there is too much soil covering the bag's interior surfaces to maintain efficient airflow.

Soil particles are measured in microns. If high-efficiency disposable bags are not used, the smallest particles (<7 microns) that are vacuumed from the carpet simply pass through and are expelled back into the building's interior where it again becomes available for occupants to breathe. Particles in the 0.3-5 micron range are small enough to remain suspended in air for several minutes, or even days, where they continue to be breathed by occupants.

It is important to understand that human lungs and bronchial passages are lined with ciliated surfaces (hair-like structures) that are able to filter or capture most inhaled particles down to 10 microns. Particles smaller than 10 microns can penetrate deep within the lungs to the alveoli, which transfer oxygen from air in the lungs through delicate membranes into the body's circulatory system. When small particles penetrate deeply into lung tissues, they can cause irritation or possible scarring of delicate tissues. When breathed in quantity over time, permanently decreased respiratory function may result, similar to that experienced by cigarette smokers. Consideration should also be given to the effect of breathing bioaerosols (bacteria or fungi spores or fragments) and their metabolites (e.g., endotoxins, mycotoxins) that become airborne during vacuuming. For this reason, high-efficiency disposable bags or filtration systems are essential.

The following charts depict the sizes of common soils that might be found in carpet and the time that particles of various sizes remain suspended in respirable air. When combined with the fine dust that inevitably is found on building furnishings after vacuuming, there is a need to increase the frequency of other cleaning tasks.

Particle Size of Common Soils

Airborne Particle	Size Range in Microns		
Tobacco smoke	0.01	to	1.0
Combustion smoke (wood, etc.)	0.1	to	4.0
Atmospheric dust	0.01	to	1.0
Household dust	0.01	to	300.0
Skin flakes	1.0	to	10.0
Insecticide dust	0.1	to	10.0
Fumes	0.1	to	1.0
Fungi spores (mold, mildew)	3.0	to	30.0
Bacteria	0.1	to	10.0
Virus	0.03	to	0.25
Pollen	10.0	to	100.0
Hair	30.0	to	120.0

Particles below 0.2 microns are visible with electron microscope (0.001 to 0.2 microns). Particles >0.2 to 10 microns are visible with a microscope. Particles >10 microns are visible to naked eye. (Source: Stanford Research Institute)

Particle Settling Rates
(Average settling time in room with 8' ceiling: µg = micron)

<1µg	>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>>> permanently suspended >>>>>>>>>>>>>>>>>>>>>>>>>>>
1µg	>> 8½ hours
5µg	>>>>>>>>>>>>>>> 20 minutes
10µg	>>>>>>> 5 minutes
15µg	>>>> 2¼ minutes
30µg	>>>34 seconds
50µg	>>12 seconds
100µg	>3 seconds

(Source: National Safety Associates, Inc.)

It is recommended that residential end-users concentrate on thorough vacuuming twice a week. In most institutional or commercial buildings, daily vacuuming is essential to prevent soils from sifting downward into the pile where they accumulate to unacceptable levels (IICRC S100). Traffic lanes should receive at least two passes, while entry areas require four or five passes.

Real versus "Apparent" Soil

Often carpet, especially in entry, pivot, and traffic areas, looks soiled even when its poor appearance is not the result of soiling. This condition is probably the result of "apparent soil," as opposed to "real" soil. Apparent soiling - "soil" that isn’t really soil but appears dirty - comes from three sources:

Abrading describes the diffusion of light reflected from a fiber's surface due to damage brought on by a combination of abrasive particle soil and traffic. Traffic grinds soil into thermoplastic fiber surfaces, creating scratched and abraded surfaces. In extreme circumstances, fibers may be cut in two, usually near the base where larger particles of abrasive soil accumulate.

Fading refers to a gradual loss of color due to prolonged exposure of carpet dyes to light sources (incandescent, fluorescent, and sunlight). Prolonged contact between the dyes used to color nylon fibers and acid soils also can change a carpet's color, or cause progressive appearance change in time.

Wear is a reduction in pile density resulting from traffic and abrasive soil thinning out the fibers comprising a tuft. Eventually, this minor fiber loss results in noticeable appearance change in heavy use areas that cannot be restored with cleaning.

The cumulative effect of soil on fibers occurs in four stages:

- Stage 1 - New fibers reflect light uniformly from the source to the viewer's eye.
- Stage 2 - Fibers become soiled and abraded, color is "lost," and the carpet appears worn (matted and crushed).
- Stage 3 – Immediately after cleaning, fibers are coated with moisture, which affects fiber appearance in two ways: first, it magnifies dyes making them more colorful than ever, and second, it fills abraded areas on the fiber's surface, which temporarily creates uniform light reflection to the viewer's eye.
- Stage 4 - Upon drying, traffic areas appear dull and dingy as light is diffused or deflected.

Preventive maintenance, coupled with adequate cleaning frequency, greatly prolongs the impact of soil on carpet appearance. While this reality of wear and tear has few IEQ implications, it does impact end-user attitudes toward carpet as the floor covering of choice. Overlooked is the fact that any other floor covering subject to maintenance neglect would deteriorate in appearance more rapidly than carpet.

In many buildings, indoor environmental quality (IEQ) is 5-10 times worse than that outside. An average of 90% of a person's life is spent indoors; therefore, IEQ is of considerable importance for the following reasons:

- Allergic responses to dust and fungi substantially increase with declining IEQ.
- Absenteeism can be traced to poor IEQ.
- Respiratory impairment in children under five is linked to poor IEQ.
- In extreme circumstances, poor IEQ leads to decreased lung capacity and increased heart workload.

Principles of Cleaning

Cleaning is the traditional activity of removing contaminants, pollutants and undesired substances from an environment or surface to reduce damage or harm to human health or valuable materials. Cleaning is the process of locating, identifying, containing, removing and properly disposing of unwanted substances from an environment or material. Cleaning may be accomplished on three levels by in-house or independent maintenance and cleaning professionals.

NOTE: This definition emphasizes the importance of human health above all else. In fact, while visually pleasing results are desired, the primary emphasis must be consumer health and safety. Fortunately, these two objectives - visual results and human health - are compatible. When cleaning for health, the visual result also is forthcoming.

Housekeeping - Routine activities to keep things in their proper places relying on organization skills and labor. It includes such periodic tasks as putting things away, emptying trash, washing dishes and clothes, vacuuming carpet, dusting furniture, and mopping floors.

Maintenance - Routine cleaning that must be performed regularly. Unlike housekeeping, it relies on mechanical and chemical intervention including door mats, cleaning machines, air filters, waxes, solvents (detergents), and disinfectants. Helps to maintain the environment in a more sanitary state.

Restoration - The activity of deep cleaning. It is accomplished periodically as needed. Restoration is required when the environment has gotten out of control and must be returned to a sanitary or higher state of order. Restoration is not a normal cleaning process and typically is performed by persons specially trained in the process.

A distinction must be drawn between cosmetic (visually acceptable) cleaning and state-of-the-art cleaning (technically accurate, as well as visually pleasing cleaning results).

Principles of Cleaning - Five Major Components

1. Dry Soil Removal (Dry Vacuuming) Principle - Based on many tests conducted by independent associations (e.g., CRI) and agencies in recent years, it is unreasonable to suggest that dry soil removal is not an essential procedure to perform before wet cleaning begins. Dry soil removal is accomplished in one preparatory (required occasionally) and three physical removal phases. First, pile preparation (using grooming tools) to untangle the pile of some high-pile residential carpet may be necessary before dry vacuuming. With commercial carpet, pile

preparation simply is not an issue. Second, physical soil removal is accomplished in three phases: overall vacuuming with an upright vacuum, entry area hand vacuuming (removal of the destructive build-up of abrasive soil), and periodic edge vacuuming to remove fine dust and soils that upright vacuum nozzles are unable to remove.

2. Soil Suspension Principle - Once dry soil has been removed from carpet, soil suspension (pre-conditioning) procedures can begin. Soil suspension is a critical step in state-of-the-art carpet cleaning. The goal of soil suspension is to separate soil from fiber surfaces. There are four fundamental factors to be considered under the soil suspension principle. They include chemical action, heat or temperature, agitation and time. These factors are discussed in that order.

3. Chemical action acknowledges the fact that, without chemicals in the form of detergents and associated additives, best efforts result only in the physical erosion or displacement of minor amounts of soil. Chemical activity is employed in two phases of the cleaning process. First and foremost, chemicals are used to prepare the carpet for cleaning by reducing surface tension, dissolving, emulsifying, suspending, and sequestering various soils. This step, called preconditioning is essential. The second phase of chemical activity occurs when chemicals are mixed or metered into rinse solutions to suspend light soils that accumulate in non-trafficked areas along baseboards or under furniture. Chemicals, properly formulated, mixed, and applied during pre-conditioning are essential to begin quality cleaning.

4. Heat or Temperature - Heat reduces the surface tension of water, and enables faster, more efficient cleaning than cold water. It is a matter of thermodynamics, or the ability of heat to accelerate the activity of the chemicals employed. State-of-the-art, truck-mounted extraction equipment is able to generate a safe and consistent water temperature over 200^{o}F/93^{o}C at the machine. However, the temperature of the water at the carpet, due to heat radiation from solution hoses and metal valves, coupled with evaporative cooling of aerosolized droplets, is no more than 160-170^{o}F/71-77^{o}C. Carpet yarns are heat-set at 212-390°F/100-200°C for several minutes. Much nylon carpet dyeing takes place at temperatures from 212-350°F/100-177°C for several hours. Therefore, fibers, yarns or dyes are unaffected by the heat employed during truck-mounted HWE cleaning. With portable units using water from installed water heaters, the temperature of rinse water on the carpet is much lower.

5. Agitation – agitation in some form is fundamental to accomplish uniform chemical penetration and distribution. Without this important step, soil suspension is superficial and non-uniform, perhaps even resulting in soil streaks following extraction.

Primarily, there are two phases in which agitation is employed in the soil suspension process. First, hand brush agitation using a multi-bristled brush or comb to work in pre-conditioners is an effective and time-efficient, although less aggressive, technique for applying agitation. Brush agitation refers to the fore-and-aft stroking of pre-conditioned carpet pile throughout traffic areas, placing particular emphasis on entry, pivot, and heavily soiled areas. Second, mechanical agitation involves the use of mechanized rotary or cylindrical, nylon-bristled brush action to achieve aggressive agitation and distribution of pre-conditioning chemicals into the carpet pile for maximum soil suspension.

Residential carpet is cleaned on average about once every two to three years. Soils deposited over this period are not suspended in seconds, even with the best chemistry. With aggressive, reputable pre-conditioning chemicals, only a few minutes are needed for chemicals, properly distributed to all areas through agitation, to do their job. About 10 to 20 minutes of dwell time is all that is required.

Summary of Cleaning Principles

There are four fundamentals included under the second principle of cleaning: soil suspension:

- Chemical application, emphasizing that without chemicals cleaning does not even begin.
- Heat or temperature excites chemicals for faster, more efficient soil suspension.
- Agitation is required to uniformly distribute chemicals.
- Time gives chemicals the dwell time required to do their job, particularly oxidized oils.

Note that each of these fundamentals is dependent upon the proper use of chemistry; i.e., temperature excites chemical molecules, agitation distributes chemicals for maximum soil contact, and dwell time allows chemicals to soften and separate soils from fibers.

Soil Extraction Principle - Extracting soils that could not be removed with dry vacuuming may be accomplished in a number of other ways (e.g., absorption, wet vacuuming, or post-cleaning dry vacuuming). The absorbent compound and absorbent pad (bonnet) methods of cleaning, for example, use soil absorption to accomplish extraction of suspended soils. The dry foam and rotary shampoo methods use wet vacuuming to remove suspended soils. The hot water extraction method uses a rinse process to flush suspended soils from fibers. Even when end-users vacuum carpet thoroughly after drying, they extract crystallized detergent residues, along with the soils they suspend.

Finishing (Grooming) Principle - The term "finishing" refers to any procedure that enhances the appearance of residential carpet beyond the physical soil removal process, to improve end-user perceptions of cleanliness. Finishing seldom is required on commercial carpet styles and it contributes nothing to cleaning or soil removal. Where appropriate, however, it contributes immeasurably to end-user perceptions of cleanliness. Generally, pile setting or grooming employs one of several finishing or pile-grooming tools (carpet groomer, brush, or comb) specifically designed for this purpose.

Drying Principle – Cleaning is not complete until carpet is dry and ready to be trafficked. Drying carpet is essential for several reasons:

- It is required to return the carpet to use by end-users as soon as possible.
- Drying carpet essentially eliminates slip-fall hazards, especially in areas where carpet transitions to vinyl, wood or tile floor coverings.
- Rapid drying eliminates sour or musty odors that are associated with prolonged dampness; moreover, it eliminates the potential for microorganism growth.

Methods of Cleaning (HWE)

The five industry-accepted carpet cleaning methods and their application steps are described in the Institute of Inspection, Cleaning and Restoration Certification's *Standard and Reference Guide for Professional Carpet Cleaning* (IICRC S100, revised 2002).

The methods of cleaning have been subdivided into two categories: maintenance or interim cleaning methods and restorative cleaning methods. Certain methods originally were developed to improve the aesthetics (appearance) of carpet between cleanings, rather than because of their thorough soil removing capabilities. Generally, maintenance cleaning methods include absorbent compound, absorbent pad (bonnet), and dry foam. Again, generally, restorative cleaning methods include properly performed shampoo and hot water extraction (HWE) cleaning.

Cleaning methods are described in terms of their chemical components, method of application (including equipment), and theory of function. They are evaluated on the system's ability to maximize the fundamentals of soil suspension (chemical action, temperature, agitation, and time). Physical soil removal capabilities (i.e., extraction) also are evaluated, along with the method's advantages and limitations.

The cleaning method that maximizes the principles of cleaning and results in maximum physical removal of soil is properly applied hot water extraction (HWE). As the name implies, the Hot Water Extraction (HWE) system has as

its main attribute the ability to flush or rinse suspended soils in quantity, assuming that both water flow and vacuum efficiency is maximized.

Components - Following dry soil removal using a CRI Green Label upright vacuum with a high-efficiency filter system or bag, the components of the HWE method include a pre-conditioner applied through a pressurized sprayer of some type; however, the mainstay of the method is a machine that pressurizes the rinse solution, heats it, injects it into the carpet's pile, and finally, recovers excess rinse water along with suspended soil. Obviously, variations in the equipment and application sequence are many.

Application - Dry vacuuming with an effective, efficient vacuum machine precedes the application of any cleaning method. Insoluble particle soil is difficult to remove when wet, and HWE units, no matter how elaborate and powerful, are not designed to efficiently remove particle and fibrous soils from carpet pile.

The second step in proper HWE cleaning involves the application of a professionally formulated, hot (if practical) pre-conditioner to the carpet.

Third, agitation of pre-conditioner for uniform distribution is essential. The aggressiveness of the agitation process depends upon the amount and composition of the soil present and also upon the delicacy of the carpet's pile design. The pre-conditioning process, coupled with agitation, causes separation of soil from fibers to occur and is absolutely critical if the full value of the HWE method is to be realized.

Fourth, thorough extraction or rinsing is employed, using one of the three basic wand stroking techniques taught industry-wide. A sufficient quantity of hot detergent solution is injected at 100 to 450 PSI and at a rate from 1-4 gallons per minute (the rate of injection being determined by the equipment's vacuum recovery capability). As the extraction floor tool is moved over the application area, the injected solution, along with suspended soil, is removed through the lips of the vacuum extraction nozzle and eventually evacuated through vacuum hoses to a recovery tank.

These procedures are followed by finishing (grooming) and drying the carpet before it can be returned to use by building occupants.

Theory of Function - The foundation of the HWE method rests upon basic detergent chemistry. Cleaning is maximized when soil first is separated from fibers by chemical agents contained in the pre-conditioner, especially when coupled with aggressive agitation.

The HWE machine serves primarily as an efficient rinse unit when employed in proper relationship with the other essential components of the cleaning process. The cleaner - not the machine - is, as always, the critical factor in producing quality cleaning. The machine has more of an influence on operator efficiency than on quality results.

The theory of HWE cleaning involves soil suspension by a preconditioning chemical that contains surfactants, alkaline builders, and, in some cases, dry solvents. Temperature, brush agitation and dwell time enhance the soil suspension process. Finally, a quantity of hot, pressurized solution is injected into the pile, further suspending and flushing soil from fiber surfaces. This injection phase is followed almost immediately by vacuum extraction, using a specially designed floor tool that maximizes the removal of soil, which is now thoroughly suspended in the rinse solution applied during the injection phase. The combination of soil suspension, performed by the pre-conditioner, followed by the thorough flushing provided by use of the HWE equipment, optimizes cleaning results.

Effectiveness Factors of HWE

Chemical - With pre-conditioning, chemical action is optimized because it provides affordable quantities (a few gallons) of professionally formulated, aggressive chemical agents in areas of moderate-to-heavy soiling.

Heat or Temperature - Temperature is important in exciting chemicals, causing them to perform more efficiently, and in reducing the surface tension of water. In the HWE cleaning process, a temperature advantage is achieved primarily when hot water is injected into the carpet in the extraction phase (130-170^{o}F/54-77^{o}C), which serves to accelerate pre-conditioning chemicals one final time, during the rinse process.

Agitation - Some form of physical agitation, i.e., brush-and-elbow action, mechanical action, etc., is required to optimize distribution of pre-conditioning chemicals in areas of moderate-to-heavy soiling. However, from a practical viewpoint, it simply is not economically feasible to add mechanical pre-conditioning as a normal part of the procedural sequence, except with extreme soiling brought about by maintenance neglect.

Time - It is unreasonable to assume that soil, ground into carpet pile for many years, is removed in the split second that elapses between the injection and extraction phases of HWE cleaning. From 10 to 20 minutes of dwell time must be provided between preconditioning and "rinse" extraction (rinsing), where significant soiling is encountered, if maximum soil suspension is to occur.

Soil Extraction - The rinse action provided during the HWE process is considered by most to be its strongest asset. Properly performed, excess chemical - which by itself or when reacted with certain oily soils, might create a resoiling residue - is removed. Further, the amount of water used in the HWE process, combined with concentrated vacuum pressure, also flushes a quantity of insoluble particle soil from the carpet's pile. However, this is not an appropriate substitute for dry vacuuming. The key to effective soil removal is the rinse phase of extraction cleaning. If this is not accomplished, remaining soil can result in abnormal resoiling or streaking. The second undesirable effect may be over-wetting the carpet, which can produce a sour odor (bacteria) and eventually, fungal growth.

Drying – Major floor cleaning projects normally are accomplished after hours or on weekends when buildings are unoccupied. In many cases, the HVAC system is programmed to shut down to save energy costs during these periods. The resulting buildup of humidity and vapor pressure can have many undesired results including micro-organism development and/or amplification, along with associated odor. This is easily avoided. Building HVAC systems fans must be set to the continuous-on position and heating or cooling systems must be set at moderate temperatures (75°F±) for at least 24 hours during and following any heavy floor cleaning, to promote more efficient evaporation and dehumidification. This not only eliminates the stagnant air in which micro-organisms flourish, but it also produces lower temperatures, which, when coupled with evaporative cooling, considerably inhibit microbial amplification.

Dry vacuum passes in areas of concentrated cleaning are highly recommended. A minimum of two air movers (laminar airflow blowers for accelerated evaporation) should be purchased. These air movers should be set up after cleaning the first residential room, or the first 500-1000 square feet of commercial carpet. The second air mover should be plugged in after cleaning the second 1000 square feet of commercial carpet, and then, air movers can be leap-frogged from there.

Using these procedures, residential carpet traffic areas and most commercial carpet will be dry before completing the cleaning project, and soil transfer from shoes to damp carpet is virtually eliminated.

Recovered Waste Disposal

There are at least five areas of concern surrounding the disposal of recovered cleaning waste.

Synthetic Fibers - During extraction cleaning of cut-pile staple yarns, some shedding of synthetic fiber is inevitable. These fibers are durable and non-biodegradable. They may cause problems in sewage treatment systems. Synthetic fibers must be pre-filtered from waste water as it is recovered and before it is disposed.

Dry Solvent Spotters - When extensive dry solvent spotting is accomplished prior to cleaning using volatile or non-volatile spotters, inevitably some of these chemicals are recovered with several of the methods of cleaning. Because science has evolved to the point at which measurements in parts per billion (ppb) are possible, dry solvent that is recovered during cleaning may constitute a contaminant for disposal purposes. Many formulators have reduced this problem by using alcohol or citrus solvents in spotters.

Pesticides – Exterminators routinely spray carpet with residual pesticides to resolve one of many home or business maintenance problems. When carpet is vacuumed or rinsed and pile yarns are extracted during cleaning, some of that pesticide is suspended, recovered and deposited in recovery bags, canisters or tanks. Governmental agencies exercise authority over what comes out and is deposited in the environment.

Lead Particles - Although a diminishing problem, trace amounts of lead have shown up in the analysis of some HWE waste water samples. The source of this contaminant is lead paint in older structures or lead from gasoline that has contaminated soil outside the structure and is tracked in. Like dry solvents these particles are measured in parts per billion. However, they are a source of concern even as regulated lead has been removed from gasoline and coatings.

Phosphates - When non-biodegradable phosphates are released to natural aquifers, they serve as fertilizers that encourage aquatic plant growth. Growing plants require more oxygen from the water, leaving little for other aquatic life forms, such as fish.

There are but two universally accepted options for disposal of recovered wastes - a sanitary landfill or a treated (sanitary) sewage system. Technically, solid waste recovered during vacuuming and the employment of some cleaning methods contains trace amounts of the aforementioned contaminants. Currently, it is being placed in trash cans for disposal in sanitary landfills.

As for liquid wastes (dry foam, shampoo, steam extraction), the best option for disposal of pre-filtered waste water (no synthetic fiber) is the sanitary (treated) sewer system. Usually, this means releasing effluents into toilets, washing machine drain lines, car wash drains, or other approved waste disposal sites.

Conclusions and Recommendations

Analytical testing of cleaning methods has added immeasurably to knowledge on this subject. However, several shortcomings that adversely impact end user attitudes toward carpet sustainability issues are apparent.

Carpet Specification

Carpet specification contributes in large part to the end-user's ultimate satisfaction with the product. Fiber content, face weight, style, dyeing methodology, color, and added features all must be considered in properly specifying carpet. The importance of proper selection is often ignored by homeowners, specifiers, architects and designers.

Routine (Preventative) Maintenance

If soils can be prevented from entering buildings, or removed before they have a chance to penetrate the carpet pile to the base of yarns, much of the cleaning problem would be prevented from manifesting in the first place.

The Holistic Approach

IEQ problems, related to maintenance and cleaning of commercial and institutional buildings must be viewed holistically. Currently, diverse cleaning applications appear disconnected. Proper maintenance and cleaning, employed proactively in a well-planned and managed built environment, can prevent or solve most problems related to IEQ issues.

Laboratory Testing

While there are several excellent studies on the types and quantities of soil in carpet, soiling methods in the lab are deficient in that they fail to reproduce the true conditions that cleaners encounter normally in the field. Much, if not most of the current body of science related to carpet cleaning concentrates on somewhat narrow, quantifiable issues, rather than the overall result of the cleaning process.

Realistic Cleaning Frequency

Carpet cleaning frequencies, both residential and commercial, which are recommended by specifiers, architects, carpet retailers and manufacturers, are totally unrealistic. To suggest, for example, that carpet in a school with hundreds of students using the building a minimum of 36 weeks during the year can be maintained with a single annual cleaning and little else is beyond imagination. Moreover, it is detrimental to the health, welfare, and learning abilities of both students and teachers (Berry et al., 2002).

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