16. The Storage Environment for Photographs: Relative Humidity, Temperature, Air Pollution, Dust, and the Prevention of Fungus

> I question whether even a small percentage of the museums in this country are doing anything more than presiding over the steady deterioration of that which they have been instituted to preserve.
>
> *America's Museums: The Belmont Report*[1]
> American Association of Museums — 1968

Given the inherent stability characteristics of a particular type of print, slide, or negative — and assuming careful processing and handling — the ultimate useful life of a photograph will be determined by the conditions of storage and display.

The most important decision that must be made is how many years one wants to keep a specific photograph — or an entire collection — in good condition. Nearly every other decision regarding choice of films and papers, processing, negative and print enclosures, display and storage temperature, and relative humidity will revolve around the answer to that question. Once it is decided how long a photograph should be preserved, the stability characteristics of the particular material and processing method used to make the photograph, dictate the conditions under which it must be kept.

As an example, the useful life of Kodak Ektacolor 74 RC prints made during the mid-1970's and early 1980's will be determined by the amount of light they are exposed to on display, the temperature and relative humidity during display, and the temperature and relative humidity of the storage area when the prints are kept in the dark. The inherently poor dark fading stability of Ektacolor 74 RC Paper means that normal room temperatures are much too high if a long life is desired for Ektacolor 74 RC prints.

If prints made on Ektacolor 74 RC Paper are to be kept in good condition for 100 years, and if the approximate light fading and dark fading (and staining) characteristics of the paper are known, it becomes a simple task to calculate how long the prints can be displayed during the 100-year period, and at what refrigerated temperature they must be kept when not on display. (Ektacolor 74 RC Paper and its higher-contrast counterpart, Ektacolor 78 Paper, were replaced with Ektacolor Professional Paper and Ektacolor Plus Paper, respectively, in 1984–1985. Compared with Ektacolor 74 RC, both of these new papers have much better dye stability in dark storage, but they continue to suffer from poor light fading stability. Particularly in dark storage at normal temperatures, the prints will form objectionable yellowish stain over time, and they too must be kept in humidity-controlled cold storage if they are to be preserved in unchanged condition.)

See page 544 for Recommendations

If it is not desired — or not possible — to keep color photographs in cold storage, then prints must be made with Ilford Ilfochrome (called Cibachrome, 1963–1991), Kodak Dye Transfer, Fuji Dyecolor, UltraStable Permanent Color, or Polaroid Permanent-Color materials — all of which are *extremely* stable when kept in the dark at normal room temperature. Of these, however, only prints made with the new UltraStable Permanent Color (introduced in 1991) and the Polaroid Permanent-Color (introduced in 1989) processes, have sufficient light fading stability to be suitable for long-term display.

Although deterioration characteristics are more difficult to quantify for black-and-white photographs than for color materials, there is ample evidence that a black-and-white photograph may fall far short of its potential life if it is stored in an unsuitable enclosure, if it is kept in contact with a poorly processed print that is contaminated with fixer, or if the surrounding air is humid and/or contains harmful levels of ozone, peroxides, sulfur dioxide, or other pollutants.

The question of how best to store photographic materials is often an economic one: Given a certain amount of available money, would a collection last longer if all old kraft-paper negative and print envelopes were replaced with polyester sleeves, or if a dehumidification system were installed to maintain the relative humidity at 20–30%? Because most prints and many negatives made in past years were not processed properly, nor washed adequately, and have high levels of residual fixer (new enclosures offer little improvement in this case), the greater benefit would almost certainly come from the dehumidification system.

Keeping Photographs and Films Forever

At least in theory, most museums and archives want to keep their collections in good condition forever, or certainly for a very long — indefinite — time. If an institution collects color photographs, refrigerated storage *must* be provided to preserve most types of color prints and films for the future. It does little good to have a computer-based cataloging system and carefully designed display galleries if color prints and films are going to deteriorate before even the next generation has a chance to view them.

With the notable exception of a small number of institutions — including the John F. Kennedy Library in Boston; the Warner Bros. movie studio in Burbank, California; Paramount Pictures in Hollywood; the Jimmy Carter Library in Atlanta, Georgia; the Art Institute of Chicago; the Moving Image, Data and Audio Conservation Division of the National Archives of Canada in Ottawa, Ontario; the National Aeronautics and Space Administration (NASA) in Houston,

February 1983

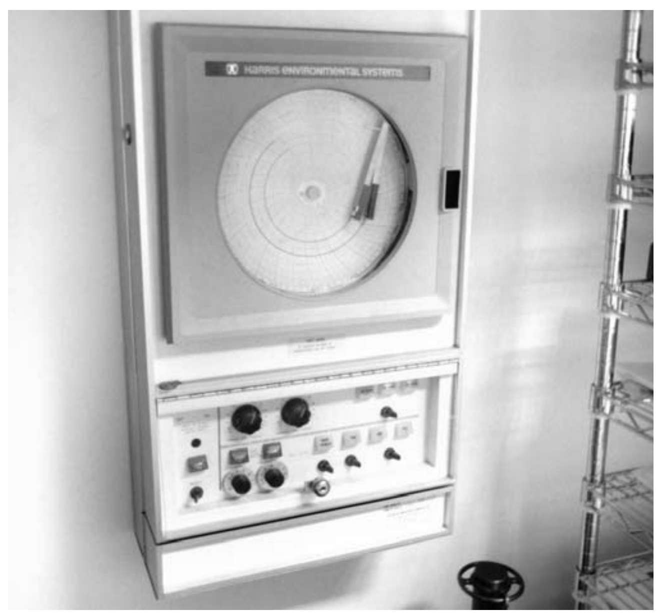
The Art Institute of Chicago stores its collection of black-and-white photographs in this humidity-controlled vault at 60°F (15.6°C) and 40% RH; color photographs are preserved in an adjacent cold storage vault maintained at 40°F (4.4°C) and 40% RH. Douglas G. Severson, conservator of photographs at the Art Institute, is shown here describing the facility to visiting members of the Photographic Materials Group of the American Institute for Conservation.

Texas; and the Historic New Orleans Collection in New Orleans, Louisiana — most institutions have not provided adequate storage facilities for their collections of photographs and motion pictures. These shortcomings virtually assure that important parts of their collections will not survive in usable form for future generations — and call into question the very purpose of these institutions.

It is sheer folly to believe that damage to collections resulting from poor storage conditions will be undone in the future using restoration techniques. Even if the technology were available to restore faded, stained, cracked, and otherwise deteriorated black-and-white and color photographs to their original condition, the costs of treating whole collections would be astronomical — far greater than what it would have cost to have taken proper care of the photographs in the first place. For many types of deterioration, such as cracks and discoloration of image silver on black-and-white RC (polyethylene-resin-coated) prints, cracked and delaminated cellulose diacetate safety film negatives, and seriously degraded cellulose nitrate and cellulose acetate motion picture films, effective restoration technology does not now exist at any price.

Past Neglect at George Eastman House

For many years the photographic storage archives, library, and the “permanent” display galleries on the second floor of the International Museum of Photography at George Eastman House in Rochester, New York had no direct air



October 1987

One of the two vault control panels, located near the vault entrance. The temperature and humidity levels are continuously recorded on circular paper charts. Alarms sound and a fail-safe control system automatically shuts down the vault dehumidifiers and refrigeration compressors if either the temperature or relative humidity deviates beyond pre-set limits. The facility was designed and built by Harris Environmental Systems, Inc.

The print storage archive and library in the attic of the International Museum of Photography at George Eastman House in Rochester, New York. When this photograph was taken in 1976, the archive had no direct air conditioning or humidity control, and storage conditions often were very poor. During summer months the temperature could reach as high as 85°F (29.4°C) with the relative humidity sometimes exceeding 80%.

conditioning or humidity control. Temperatures in the archives and library ranged from 45 to 85°F (7.2–29.4°C), with the relative humidity varying from a low of around 30% to higher than 90%; humidity fluctuations in the archives and display galleries were often quite rapid as outdoor weather conditions changed. Temperature control in the archives and library was improved in 1984 when a new air-conditioning system in the storage area was put into operation, but even then the relative humidity continued to fluctuate beyond an acceptable range. The second-floor display galleries continued without air conditioning until they were closed at the end of 1988.

On a hot afternoon in July 1978, the *original* negatives from more than 300 Hollywood motion pictures in the George Eastman House Collection were lost in a disastrous fire. The cellulose nitrate films were being kept under astonishingly poor conditions in an old concrete building that had no air conditioning, no ventilation system, no sprinkler system, and no fire alarm. The Rochester Fire Department attributed the fire to spontaneous combustion. Most of the estimated one-million-dollar insurance settlement the museum received went to cover operating deficits during the years following the fire; little of the settlement, apparently, was directed toward improving the storage facilities.

Subsequently, it was revealed that in the early 1970's Eastman House buried hundreds of rolls of original MGM nitrate motion picture negatives on its grounds under what was once one of George Eastman's gardens; all of the films are now presumed to be destroyed. Commenting on the loss, James Card, former director of the film department at Eastman House and the person who supervised the burial, said: "Our vaults were filled to the brim. We had no place to put it. I went to a board of trustees (of Eastman House) meeting and asked that I be allowed to build or rent another vault. They said 'no'."[2] Among the buried and now destroyed films was the original camera negative from *Andy Hardy Meets Debutante* with Mickey Rooney and Judy Garland. Ironically, many of the MGM films that were deemed valuable enough to be spared from the burial were later lost in the 1978 fire.

After a period of uncertainty over whether the museum would even remain in Rochester. At one point, in 1984, the trustees actually proposed *giving* the collection to the Smithsonian Institution in Washington, D.C. But the plan was quickly abandoned because of organized opposition in Rochester and expressions of shock and disgust voiced by influential members of the photography community from around the world, and a fund drive was begun for a new $7.4 million archives building to be constructed adjacent to George Eastman House "to better preserve the vast collection of historical photographs, films, technology and library owned by the Museum." Aided by a $16 million endowment grant


June 1987

Improved storage conditions are provided in the new $7.4 million archives building located adjacent to George Eastman House (shown here in the early stages of construction in June 1987, the archives building was completed at the end of 1988). Plans for an urgently needed cold storage vault for the museum's priceless collection of color photographs were set aside, apparently in an effort to reduce construction costs. To avoid overshadowing George Eastman House itself (originally the home of George Eastman, the founder of the Eastman Kodak Company), two stories of the 60,000-square-foot, three-story archives building were constructed below ground level. The photograph and motion picture collections are stored on the lower two floors.

from Eastman Kodak, the new archives building was completed in 1988. Photograph storage areas in the new facility are maintained at 65°F (18.3°C) and 40% RH, which, for black-and-white photographs, is a significant improvement over the conditions that were present in the old archives in George Eastman House.

The original plans for the new archives building called for a cold storage vault for color photographs (specifications for the vault tentatively were set at 35°F [1.7°C] and 25% RH). But when the new building was completed at the end of 1988, the long-awaited vault was nowhere to be seen. Sadly, despite protests from a concerned conservation staff, plans for the cold storage vault were set aside. At the time this book went to press at the end of 1992, Eastman House continued to store its priceless historical collection of color photographs under woefully inadequate conditions. It is fervently hoped that Eastman House will correct this unfortunate shortcoming in the care of its collections.

Relative Humidity and Temperature

At any given relative humidity, almost all forms of deterioration of color and black-and-white photographs slow down as the temperature is lowered. If satisfactory humidity levels can be maintained, storage temperatures should be as low as economically possible, and temperatures in display and work areas should be as low as human comfort permits. For black-and-white prints and films stored in the normal temperature ranges found in homes and museums, however, maintaining low relative humidity is usually much more important than reducing the temperature.

Relative humidity is also an important factor in the fading and staining of color photographs, but as long as the humidity does not exceed an upper limit of 65–70% for long periods (which would risk fungus growths), storage temperature is much more significant than relative humidity with most types of color prints, slides, and negatives. As a general rule, the fading rate of color dye images approximately *doubles* with every 10°F (5.6°C) increase in temperature. The dark fading characteristics of color films and prints are discussed in Chapter 5.

For storage of black-and-white films and prints, temperatures not exceeding 70°F (21°C) have often been recommended; for medium-term storage (a minimum useful life of at least 10 years), *ANSI IT9.11-1991*, the American National Standard for film storage conditions, states:

November 1986

The photograph collection at the Museum of Modern Art in New York City is stored in this environmentally controlled room at 60°F (15.6°C) and 40% RH. The facility was constructed in 1984. Ektacolor and other chromogenic color prints are kept at 35°F (1.7°C) and 25–35% RH in the frost-free refrigerator in the back of the room at the far right. Peter Galassi, a curator of photography at the time this photograph was taken, discusses the handling of prints in the collection with Carol Brower. In 1991, Galassi was appointed director of the Museum's department of photography.

> Ideally, the maximum temperature for extended periods should not exceed 25°C (77°F), and a temperature below 20°C (68°F) is preferable. The peak temperature for short time periods shall not exceed 32°C (90°F). For color film a storage temperature not exceeding 10°C (50°F) shall be used for proper protection. Short-term cycling of temperature shall be avoided. Cycling of relative humidity shall be no greater than ± 5% over a 24 hour period. Protection may be increased by storing film at low temperature and low relative humidity.[3]

For extended-term storage of black-and-white photographs, *ANSI IT9.11-1991* states:

> Temperatures shall not exceed 21°C (70°F), and added protection may be obtained for all films by low-temperature storage. Low temperature storage improves the stability of both the film base and the image. A storage temperature of 2°C (35°F) or below shall be used for color film. Excellent keeping behavior has been obtained by storing color film at such low temperatures.

ANSI Replaces the "Archival Storage" Designation with "Extended-Term Storage"

In previous versions of the ANSI storage standards, extended-term storage was referred to as "archival storage." In 1990 ANSI decided to remove the "archival" designation from all of the ANSI photographic standards. The rationale for this is explained in the Foreword to *ANSI IT9.11-1991*:

> The term "archival" is no longer specified in American National Standards documents since it has been interpreted to have many meanings, ranging from preserving information "forever" to the jargon meaning [especially in the computer and electronic data storage fields], temporary storage of actively used information. It is therefore recommended that the term "archival" not be used in standards for stability of recording materials and systems.

Processed photographic films are now classified according to the life expectancy or "LE designation," when stored under specified conditions. Terms such as archival processing, archival record film, and archival storage materials, all of which have been widely used in the photography conservation field, are no longer used or endorsed by ANSI.

Recommendations

- **Keep photographs cool and dry.** Do not store photographs in basements (too damp) or in attics (too hot).

- **Black-and-white prints and negatives:** Relative humidity in the storage area is the most critical factor in determining the rate of image deterioration. Museums and archives should consider humidity control to be the **number-one priority** for their black-and-white collections — about 30% RH is recommended if cycling between storage and use areas can be avoided (see below); levels higher than 50% RH are unacceptable. For storage of photographs in homes and businesses, the relative humidity should be kept as low as practical, and every effort should be made to prevent the relative humidity from rising above 65% for extended periods.

- **Color films and prints:** Storage temperature generally is the most significant factor in determining the rate of image fading and staining, with relative humidity being comparatively less important than it is with black-and-white photographs. Each 10°F (5.6°C) reduction in temperature will approximately **double** the life of a color material (see Chapter 5). Museums and archives with color films, prints, and motion pictures in their collections **must** provide humidity-controlled cold storage facilities (see Chapter 20). Institutions and photographers with small color collections can keep them in suitable frost-free refrigerators (see Chapter 19).

- **Prevent wide-ranging humidity cycling.** Particularly with fiber-base prints, drastic fluctuations in humidity can cause severe curling. Over time, the curl will become much more pronounced than when prints are stored in a **constant** relative humidity, even if the humidity level is very low. Widely cycling humidity contributes to the cracking of RC prints that have been embrittled as a result of light exposure during display. Cycling humidity can also cause emulsion cracks in fiber-base prints. Ideally, the RH should be maintained within ± 2% of the aim point. Recent studies of emulsion stress and moisture relationships conducted by Mark McCormick-Goodhart of the Smithsonian Conservation Analytical Lab have underscored the dangers to prints and films posed by storage in cycling — or in very low — relative humidities.

- **Environmentally-controlled storage facilities:** Bonner Systems, Inc. is recommended for the design and construction of temperature- and humidity-controlled storage rooms and refrigerated vaults (see Chapter 20).

- **Dehumidifiers:** For museums and archives, Cargocaire automatic dry desiccant dehumidifiers equipped with HEPA filters and incorporated into building heating and cooling systems are recommended (reliability problems have been reported with some older Cargocaire units but improved models were introduced in 1989). Cargocaire is located at 79 Monroe Street, Amesbury, Massachusetts 01913; telephone: 508-388-0600. For small storage areas, home-type dehumidifiers used in conjunction with room air conditioners are satisfactory.

- **Silica-gel:** Bags or cans of silica gel are generally unsatisfactory as a means of humidity control.

- **Hygrometer calibration:** The calibration of mechanical and electronic hygrometers should be checked at least every 6 months and adjusted as necessary. In museums and archives with tightly controlled relative humidity, a single calibration point close to the humidity level maintained in the institution is sufficient.

- **Fungus:** When photographs are stored at the recommended humidity levels (i.e., 30–40% RH), fungus growth will not occur. Kodak Print Flattener, Pako Pakosol, and other hygroscopic print flatteners for fiber-base prints should be strictly avoided because such products can promote fungus growth in humid environments.

- **Air pollutants:** "Safe" levels of airborne pollutants have yet to be established (for black-and-white photographs, the notion of "safe" levels is probably not even a valid concept). Museums and archives should keep pollutant levels as low as practical — oxidants such as peroxides and nitrogen oxides, in addition to sulfur-containing gases, can be particularly harmful to the delicate silver images of black-and-white photographs. The effects of commonly encountered air pollutants on color photographs are not known, but they probably are much less significant than with black-and-white photographs. Efforts to limit concentrations of pollutants are usually of little value if relative humidity cannot be maintained at or below the recommended levels.

- **Agfa-Gevaert colloidal silver test slides:** These inexpensive and compact test slides are uniquely suited for monitoring airborne pollutants that can harm the silver images of black-and-white photographs; museums and archives should place the test slides in all areas in which black-and-white photographs are stored and displayed. The Agfa-Gevaert test slides are available from the Image Permanence Institute, Rochester Institute of Technology, Frank E. Gannett Memorial Building, P.O. Box 9887, Rochester, New York 14623-0887 (telephone: 716-475-5199; Fax: 716-475-7230).

- **Floods:** Valuable photographs should not be stored in locations where there is even a **remote** possibility of flooding. Storage areas should be isolated from water pipes so that water is prevented from reaching any part of the collection if a pipe should burst. Unless special precautions are observed, basement or other below-ground storage is not recommended because of the danger from water damage.

- **Fires:** Buildings and storage rooms constructed of non-combustible materials are recommended. Fire-detection systems should be installed and are particularly important in combustible structures. Water sprinklers should be avoided in photograph storage areas; fire-suppression systems using Haylon gas or newer, environmentally-acceptable substitutes are recommended.

Low Relative Humidity Is Especially Important in the Storage of B&W Materials

With black-and-white prints and films processed in the normal manner and stored in the typical variety of envelopes and boxes, the relative humidity of the storage area is usually *the* most critical factor in determining the eventual life of the photographs. Maintaining low and reasonably constant humidity should be the number-one priority when designing a storage area for photographs — whether in a large museum or archives, in a valuable commercial collection, or for a serious photographer desiring to keep negatives, slides, and prints in the best possible condition. It is realized, of course, that many businesses — and certainly most amateur photographers — will not be able to justify the cost of a special temperature- and humidity-controlled storage facility.

Nevertheless, the importance of low-humidity storage must be emphasized, and the often-repeated admonition to "store photographs in a cool and dry place" is a good rule to follow. In a home, photographs should not be stored in the basement, where the relative humidity is commonly in the 90–100% range during the warm months of the year, nor in an attic, where temperatures can reach above 140°F (60°C). A first-floor storage location in a home is usually best, with photographs kept off the floor in cabinets or on shelves.

Regardless of the storage temperature, the relative humidity for storage of both color and black-and-white films and paper prints should, ideally, be kept between 20–30%.

During the past several years, research by James M. Reilly and his co-workers at the Image Permanence Institute at the Rochester Institute of Technology, the Eastman Kodak Company, and at other laboratories, as well as data obtained from examination of films stored under a variety of conditions in all parts of the world, has focused attention on the critical role played by relative humidity in both film base stability and silver image stability. Lending considerable urgency to this work is the alarming realization that in all too many cases, cellulose acetate film base and the silver images of both films and prints have deteriorated far more rapidly than had been expected.

Table 16.1 ANSI-Recommended Relative Humidity and Temperature for Film Storage

	Medium-Term Storage*		Extended-Term Storage**	
Sensitive Layer	Relative Humidity Range***	Maximum Temperature	Relative Humidity Range***	Maximum Temperature
Silver-gelatin Heat-processed silver Vesicular Electrophotographic Photoplastic Diazo	20–50%	25°C (77°F)	20–30%	21°C (70°F)
Color	20–30%	10°C (50°F)	20–30%	2°C (35°F)

* Medium-Term storage conditions are suitable for the preservation of recorded information for a minimum of 10 years.

** Extended-Term storage conditions are suitable for the preservation of recorded information having permanent value. In previous ANSI standards, extended-term storage conditions were known as "archival" storage conditions; the term "archival" is no longer used in ANSI photographic standards.

*** The moisture content shall not be greater than film in moisture equilibrium with these relative humidities.

Adapted from **ANSI IT9.11-1991, American National Standard for Imaging Media – Processed Safety Photographic Film – Storage**, with permission of the American National Standards Institute, Inc. © 1991. Copies of this Standard may be purchased from the American National Standards Institute, Inc., 11 West 42nd Street, New York, New York 10036; telephone: 212-642-4900; Fax: 212-302-1286.

Relative Humidity and Deterioration

High relative humidity greatly increases the rates of nearly every type of physical and image deterioration associated with black-and-white photographs. Image oxidation and sulfiding — discoloration and fading caused by residual processing chemicals, contact with unsuitable enclosure and mounting materials, airborne pollutants, migration of chemicals from adjacent improperly processed photographs, fingerprints, etc. — all proceed much more quickly in conditions of high relative humidity. In high relative humidity, the oxygen in air itself can slowly attack silver images.

A landmark 1991 report entitled *Preservation of Safety Film*, by James M. Reilly, Peter A. Adelstein, and Douglas W. Nishimura, working at the Image Permanence Institute at the Rochester Institute of Technology, confirmed that relative humidity plays a determining role in the deterioration rates of cellulose nitrate, cellulose triacetate, and other cellulose ester films:[4]

> Deterioration is *strongly humidity dependent.* The data showed that lowering the RH of the storage environment from 50% to 20% RH will prolong the life of the film from 3 to 10 times, depending on the property measured.
>
> Deterioration is also *strongly temperature dependent.* Lowering the storage temperature from 68°F [20°C] to 37°F [2.9°C] will increase the overall predicted life of film by a factor of 10 times.
>
> Optimum storage conditions for film *include both low temperature and low humidity.* Indications are that the benefits are additive, i.e., that the combination of low temperature and low RH is better than either alone.

One of the key findings of the research by Reilly and his co-workers was that, contrary to what has been almost universally accepted in the past, cellulose nitrate and cellulose acetate films have generally similar stability characteristics:

> All of the cellulosic film materials, including *all the acetate safety films* and at least one sample of cellulose nitrate, have the *same general behavior* with respect to deterioration — they can be expected to deteriorate at the same general rate if kept under similar storage conditions. Accepted beliefs that nitrate will necessarily degrade faster than acetate, and that among safety films, that diacetate is much worse than triacetate, are not supported by the data.

Storage in high humidity can produce severe stains on areas of negatives and prints in contact with glued seams of paper envelopes. Conditions of high relative humidity also favor the growth of fungus on gelatin emulsions and can cause gelatin to soften to the point where it can stick, or "ferrotype," to adjacent surfaces of films, to smooth plastic filing enclosures, or to framing glass. High humidity markedly accelerates exudation of greasy plasticizers on the surfaces of polyvinyl chloride (PVC) storage enclosures, and this greatly increases the likelihood of films and prints sticking to plasticized PVC.

High-humidity storage also enhances the tendency of emulsions to stick to polyethylene which has been treated with slip and anti-block agents (low-density polyethylene for making photographic enclosures such as Print File Archival Preserver polyethylene notebook pages nearly always contains these additives — see Chapter 14).

In an important early study of the influence of residual thiosulfate and storage conditions on silver-gelatin image stability, French researchers Pouradier and Mailliet wrote:

> If the photographic document is conserved in a dry atmosphere (relative humidity less than or equal to 50%), the thiosulfate retained is practically inoperative as long as the concentration does not exceed ten milligrams per square decimeter. In contrast, even with a very weak concentration, it becomes one of the factors affecting deterioration when the humidity and temperature of the surrounding environment increase.
>
> If, during the entire period of the document's required life, it were possible to keep the air of the storage vault unfailingly at low relative humidity, relatively high levels of residual thiosulfate could be tolerated.[5]

Under the accelerated conditions of this study, Pouradier and Mailliet determined that for a given level of silver image deterioration in prints with a low amount of residual thiosulfate, prints kept at 20% RH lasted at least *10 times longer* than prints stored at 70% RH; when larger amounts of thiosulfate remained in the prints, the increase in life afforded by storage at 20% RH became much greater. In some cases, extrapolations from the test data indicated that when significant amounts of thiosulfate were present, prints stored at 20% RH would last more than 100 times longer than similar prints stored at 70% RH. Of course, during long-term storage, other factors — such as air pollutants — may intervene to lessen these differences, but the advantages of low-humidity storage remain very significant. For the price of a dehumidification system to maintain relative humidities in the 20–30% range, the useful life of a collection of black-and white photographs will almost certainly be increased many times over.

In a survey of silver-image deterioration (microspots, or redox blemishes) in microfilm collections, McCamy, Wiley, and Speckman observed:

> The effect of humidity on blemish incidence was quite pronounced. When the maximum humidity was 51 to 60 percent, there were 11 times as many blemished leaders and 19 times as many blemished information sections as there were when the relative humidity was 20 to 50 percent.
>
> In the arid southwestern part of the United States, Wiley observed a collection of films, in-

> cluding several brands processed in many places over a twenty-five year period and stored in cans or paper boxes. The storage temperature was thought to exceed 100°F [38°C] frequently but the humidity was always low. No redox blemishes were found on these films.[6]

Accelerated dark-aging studies conducted by James M. Reilly and Douglas G. Severson in 1980 showed that high-humidity storage is very harmful to albumen prints:

> Primary forms of deterioration were found to be highlight detail loss, overall density loss, image hue changes and the formation of a yellow stain in highlight (non-image) areas. Ambient relative humidity was found to be the principal rate-controlling factor in all these forms of deterioration, with the rate greatly increasing above 60% RH. . . . Processing flaws were found to be of less overall importance in albumen print preservation than environmental conditions during storage.
>
> . . . If the minority of albumen prints left in good condition are to be preserved, a clear message from the experimental results is that they must be shielded from moderately high moisture levels.[7]

More recently, in 1990, James M. Reilly and co-workers reported on work at the Image Permanence Institute which showed a dramatic reduction in the degree of microfilm silver image attack by hydrogen peroxide in accelerated tests when the relative humidity was reduced to the 10–30% range.[8]

Wide Fluctuations in Relative Humidity Should Be Avoided

Short-term humidity cycling should be minimized; ideally, fluctuations should be limited to not more than ± 5% RH. More gradual seasonal variations are probably less critical. Wide fluctuations in relative humidity produce physical stresses which may in time cause base and/or emulsion cracking, delamination, and other forms of physical deterioration; prints on RC (polyethylene-resin-coated) paper appear to be particularly susceptible to this kind of damage. However, examination of historical collections which have been stored for many years in totally uncontrolled humidity conditions indicates that many types of materials can tolerate reasonable fluctuations without obvious physical damage; variations of ± 10% RH probably do little harm. What is more important, especially for black-and-white films and prints, is to keep the average relative humidity at a low level.

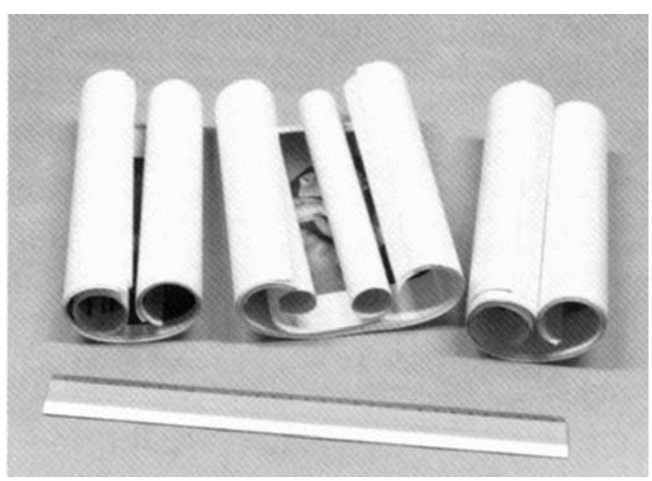
Films without anti-curl gelatin back-coatings, as well as paper prints (especially single-weight fiber-base prints), have an obvious tendency to curl in low-humidity conditions, and concern has been expressed that stresses induced by low-humidity storage (caused by unequal coefficients of moisture-associated expansion of the gelatin emulsion layer and paper or plastic support material) may over time cause emulsion cracking or other physical damage. It has been suggested that storage at a higher humidity (e.g., 50% RH) might be preferable.

This author believes that in most cases the greatly increased stability of the image and support material afforded by low-humidity storage more than offsets the possibility of damage caused by physical stress. Many instances of cracking and other problems attributed to storage in very dry conditions have in fact been caused by *cycling* between very low-humidity indoor air in the cold months of the year and warm, humid conditions in the summer. The catastrophic internal image-receiving layer cracking that has occurred in early Polaroid SX-70 prints appears to have been caused by storage in such conditions; the cracking has destroyed the images of many SX-70 prints made from 1972 until around 1980, when improvements were made in the prints.

Widely Cycling Relative Humidity Can Cause Extreme Curl in Fiber-Base Prints

It is this author's observation that unless they are physically restrained and held flat — stored in a filled, shallow box or held in place by an overmat, for example — fiber-base prints stored in an environment with widely cycling relative humidity develop much more curl over time than prints kept in a more constant relative humidity (this is true even when the "constant" relative humidity is significantly lower than the lowest level reached in a cycling condition). In cycling conditions, the maximum curl may be reached only after many years of storage. This author currently has no explanation why fiber-base prints react in this manner, and nothing has been published on this subject (see Chapter 15 for further discussion of humidity-related print curl).

Reasonably constant low-humidity storage usually presents few problems. It is realized, of course, that few parts of the world have year-round low-humidity climates, and only museums and other collecting institutions are likely to have funds for the equipment required to maintain constant temperature and relative humidity conditions throughout the year in storage and display areas.



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Over a period of years, widely cycling relative humidity can cause severe curling of fiber-base prints.

The Recommended 20–30% RH Is Usually Found Only in Cold Storage Vaults for Color Motion Pictures and Still-Photographs

Some institutions in arid climates have naturally low average indoor relative humidity, but at the time of this writing this author was unaware of a major museum or archive anywhere in the world that maintains a constant and controlled relative humidity of 30% or lower in general photographic storage areas. It is only in dehumidified cold storage facilities for color photographs and motion pictures — found only in a relatively small number of sophisticated institutions in the U.S. and a few other countries (see Chapter 20) — and in a few black-and-white microfilm storage installations that such a condition is maintained.

In North America, institutions with cold storage facilities that operate at 30% RH or lower include: the John Fitzgerald Kennedy Library, Boston, Massachusetts; the National Aeronautics and Space Administration (NASA) facilities in Houston, Texas (where the huge NASA spaceflight color photography collection is preserved) and in White Sands, New Mexico; Paramount Pictures in Hollywood, California; Warner Bros. in Burbank, California; the Historic New Orleans Collection in New Orleans, Louisiana; the National Archives and Records Administration, Alexandria, Virginia; the Library of Congress in Landover, Maryland; the Library of Congress Film Conservation Center at Wright-Patterson Air Force Base near Dayton, Ohio; the Peabody Museum of Archaeology and Ethnology at Harvard University, Cambridge, Massachusetts; the Human Studies Film Archive, the National Museum of African Art, and the Office of Printing and Photographic Services at the Smithsonian Institution in Washington, D.C.; the Ancient Biblical Manuscript Center at Claremont College, Claremont, California; and the Moving Image, Data and Audio Conservation Division of the National Archives of Canada in Ottawa, Ontario.

In 1982 the Art Institute of Chicago constructed a storage vault to keep its black-and-white photography collection at a relative humidity of 40% and a temperature of 60°F (15.6°C); chromogenic color photographs are stored in a second vault that operates at 40% RH and a temperature of 40°F (4.4°C). The relative humidity is controlled at 35% in the Microtext Masters Storage Room at the Newberry Library in Chicago, Illinois; the microfilm storage area is in the library's sophisticated new bookstack building completed in 1982. The temperature is maintained at 60°F (15.6°C) throughout the structure (the Newberry Library facility is discussed in more detail later in this chapter).

In 1984 the Museum of Modern Art in New York City moved its fine art photography collection into a newly constructed storage room that is maintained at 40% RH and 60°F (15.6°C); the museum stores its collection of chromogenic color prints in a frost-free refrigerator with a relative humidity of 25–35% and a temperature of 35°F (1.7°C).

Storage areas in the new building housing the Center for Creative Photography, completed in 1988, are kept at 60°F (15.6°C) and 40% RH. Located in Tucson, Arizona, the Center is associated with the University of Arizona.

The National Gallery of Canada, which moved into a new building in Ottawa in 1988, maintains 59°F (15°C) and 40% RH in its photograph collections vault; a smaller cold storage vault for chromogenic color prints and films is kept at 39°F (4°C) and 40% RH.

The Canadian Centre for Architecture in Montreal completed a new building in 1988 which provides two storage vaults for its photograph collections — one vault is kept at 40°F (4.4°C) and 40% RH, and the other at 55°F (12.8°C) and 40% RH. The building as a whole is maintained at 70°F (21°C) and 43% RH.

National Underground Storage, Inc., located 220 feet underground in a former limestone mine near Boyers, Pennsylvania (57 miles north of Pittsburgh), maintains 25% RH and about 68°F (20°C) in its high-security microfilm storage vaults. Federal government agencies, including the Social Security Administration, banks, and major corporations from around the world utilize the underground facility to store microfilm, paper records, computer tapes, and motion pictures (a number of major Hollywood movie studios keep backup copies of their motion picture libraries here).

The Granite Mountain Records Vault, which houses a vast collection of microfilmed genealogical records for the Church of Jesus Christ of Latter-Day Saints (popularly known as the Mormon Church), maintains 30–40% RH and about 55°F (12.8°C) in its high-security vault that was tunneled into the side of a solid granite mountain located near Salt Lake City, Utah.

University Microfilms International, Inc., a major microform publisher headquartered in Ann Arbor, Michigan, stores its microfilm masters at 70°F (21°C) and 40% RH.

The color and black-and-white photography collection at the Mystic Seaport Museum in Mystic, Connecticut is stored at 65°F (18.3°C) and 35% RH.

Measurement and Control of Relative Humidity

In considering various storage arrangements for photographs, it is necessary to have an understanding of the relationship between humidity and the temperature of the air. Relative humidity, expressed as a percentage (%), is simply the amount of water vapor in a body of air at a given temperature compared to the amount of water vapor the air would contain at maximum saturation (100%). Absolute humidity is a measure by weight of the amount of water vapor in a given body of air: for example, 6.4 grams water vapor per kilogram of air. A kilogram of air at sea level at 68°F (20°C) is a volume of 0.84 cubic meter.

The capacity of air to contain moisture increases markedly as the temperature of the air increases. For example, the maximum amount of moisture that air can contain at 50°F (10°C) is 7.1 grams per kilogram of air. At 82°F (27.5°C) the moisture capacity increases to 21.4 grams per kilogram of air, or about three times the capacity of air at 50°F.

This means that within an isolated body of air, when the temperature increases, the relative humidity decreases. Conversely, when the temperature drops in a given body of air, the relative humidity *increases*. This is the most important phenomenon for the photographic archivist to understand because of the rapid damage that can be caused to photographs by high *relative* humidities.

Keep in mind that it is the actual relative humidity of the storage area, and *not* the outdoor relative humidity given by weather forecasters, that is important. Some lo-

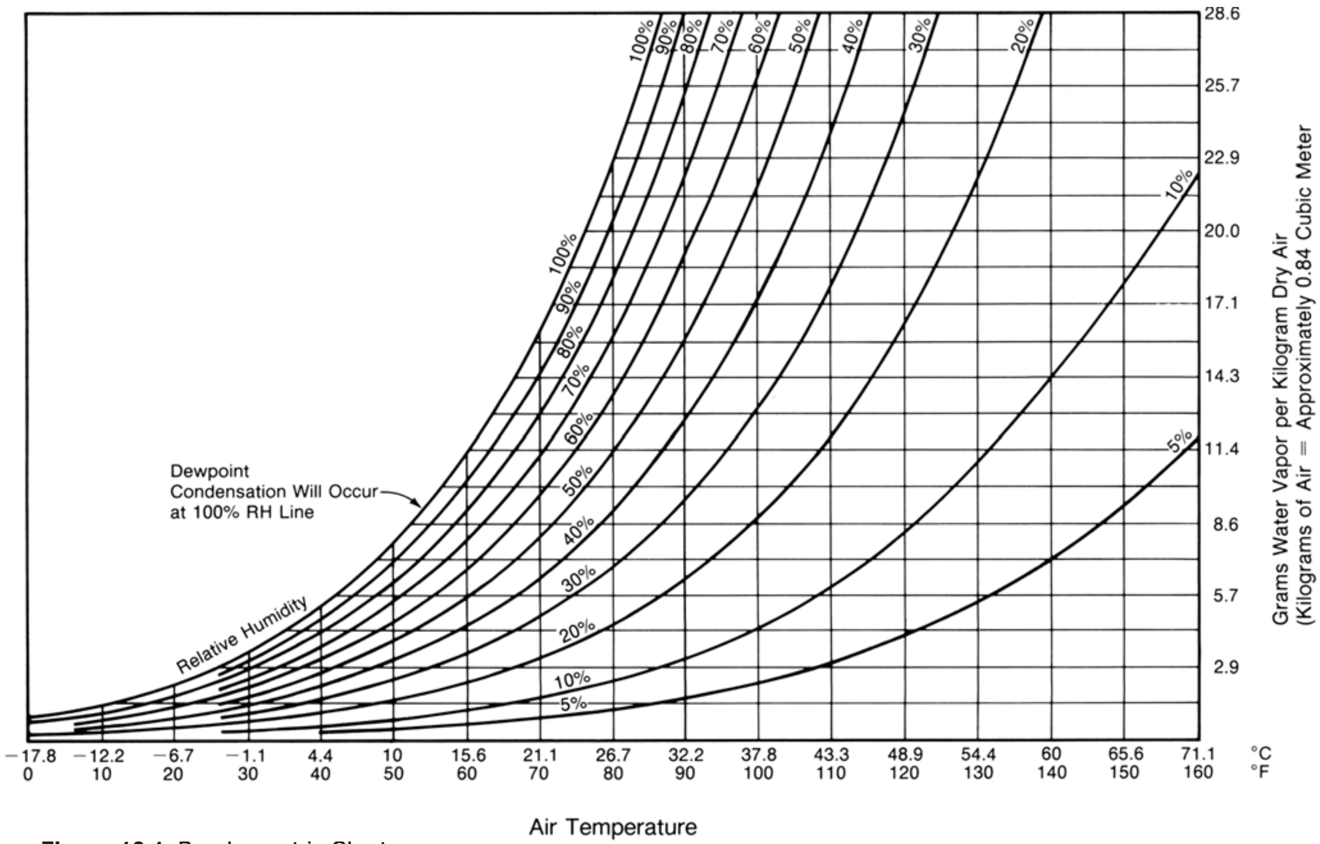


Figure 16.1: Psychrometric Chart

cations in the United States with a reputation for being humid in the summer actually have lower relative humidities than cooler areas which are considered to be more comfortable. An example of this is Washington, D.C., which has a mean relative humidity of about 71% during the summer and is famous for being "muggy" and uncomfortable. San Francisco, on the other hand, has a mean relative humidity of about 79% during the same summer period, but the city is not thought of as being humid because the lower summer temperatures make it feel more comfortable.

The relationship between relative humidity, air temperature, and moisture content can be understood most easily with the aid of a psychrometric chart (**Figure 16.1**). Following are a few examples of common photograph storage situations that illustrate the use of a psychrometric chart. As can be seen, the outdoor relative humidity may have little relationship to the actual indoor relative humidity.

Figure 16.2: The Basement of a Building. On a typical summer day with an outdoor temperature of 85°F (29°C) and a relative humidity of 60%, outside air enters a cool basement and the temperature of the air drops to 70°F (21°C). The temperature drop causes the relative humidity to rise to near 100%. A basement frequently *adds* water vapor to the air by transmitting moisture from the ground through the walls and floor.

Figure 16.3: Air-Conditioned Building on a Hot Day. Outdoor air at 85°F (29°C) and 50% RH is brought into a building by a ventilation system. The outdoor air mixes with cooler air already present in the building, thus lowering the temperature of the outdoor air and causing the relative humidity to rise; however, the effect is reduced by the dilution with the indoor air. The air conditioner will remove some of the moisture by momentarily cooling some of the air to about 55°F (13°C) and condensing excess moisture. Air which has passed over the air conditioner cooling coils will have a relative humidity of about 58% when it warms back up to the room temperature; however, the relative humidity will probably be increased above this level by mixing with the rest of the indoor air.

The final indoor relative humidity depends on a complex set of factors including the outdoor temperature and relative humidity, ventilation rates, building insulation, internal heat load (people, lights, machinery, etc.), moisture added to the air in the building by people and other sources, solar heat load, type of air conditioner, and many others. Often the resulting indoor relative humidity will be in the same range as the outdoor relative humidity even though the temperature indoors is cooler. It is not uncommon, however, for the indoor relative humidity in an air-conditioned building to actually be *higher* than the outdoor relative humidity. This is especially likely to occur during the comparatively cool spring and fall months and during cool nights in the summer (see **Figure 16.4**). As can be seen, the air conditioner must remove substantial quantities of water when cooling the air to maintain even the *same* relative humidity as that of the warmer outdoor air. Advertising for air conditioners often gives misleading information about this. To maintain constant low relative humidity

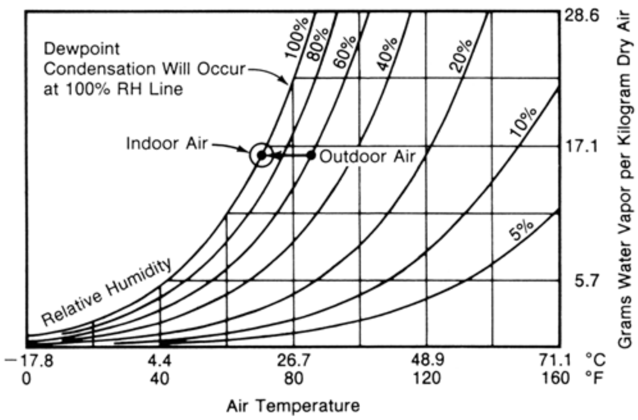


Figure 16.2: The Basement of a Building

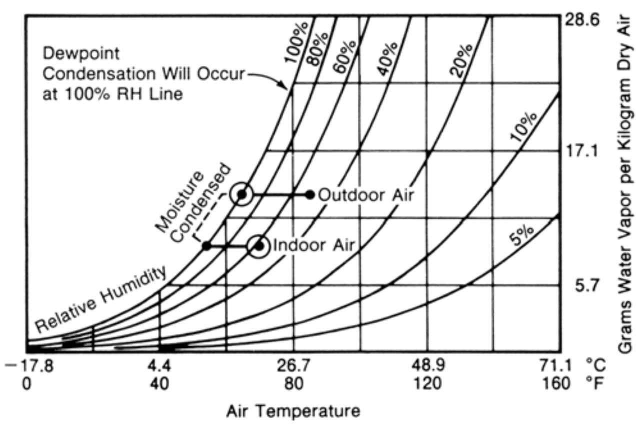


Figure 16.3: Air-Conditioned Building on a Hot Day

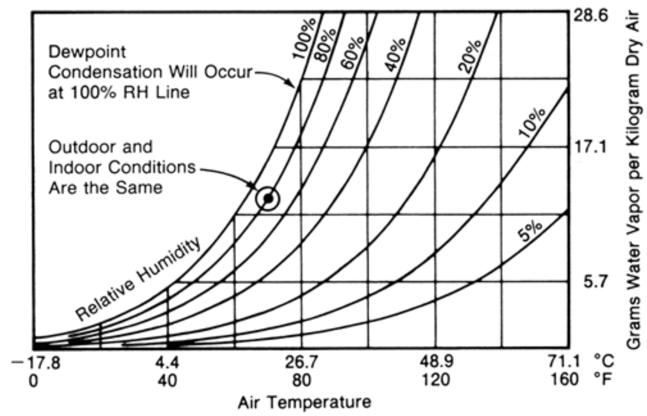


Figure 16.4: Air-Conditioned Building on a Cool Day

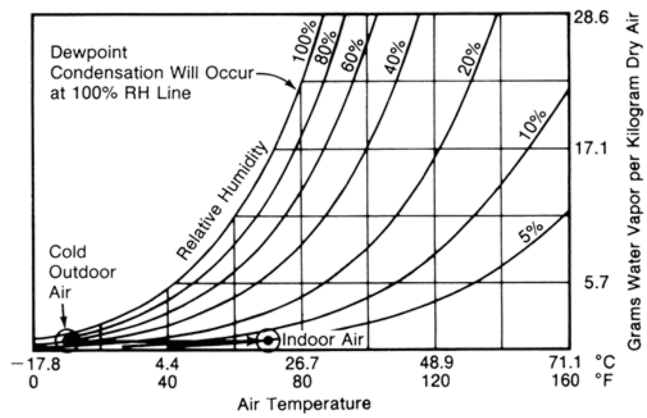


Figure 16.5: Cold Winter Day

inside a building requires special air-conditioning equipment which has provision for dehumidifying air without cooling it. One or more refrigeration-type dehumidifiers of the kind sold for home use may be placed in small rooms of air-conditioned buildings to aid in controlling the humidity.

Figure 16.4: Air-Conditioned Building on a Cool Day. On a cool day, such as often occurs during the spring and fall months in the U.S., the outdoor temperature might be 70°F (21°C) with a relative humidity of 80%. Under such conditions, especially if there is a low internal heat load, the air-conditioning system will not be needed to keep the indoor temperature at 70°F (21°C). As a result, the indoor relative humidity will be about the same as the outdoor relative humidity: a high 80%. Accessory dehumidification or air-reheating equipment will be needed to control the humidity level.

Figure 16.5: Cold Winter Day. This situation is opposite to that of an air-conditioned building in warm outdoor temperatures. Cold outdoor air at 10°F (–12°C) and 60% RH is warmed up by the building heating system to 70°F (21°C). As a result the relative humidity will drop to below 10% unless moisture is added indoors by humidification equipment. Typical indoor relative humidity found in homes and office buildings on cold days is usually somewhat higher than would be assumed from the psychrometric chart, due to moisture added to the air by people breathing, dishwashing, etc., but is often in the 10–20% range. When relative humidity cycles between normal (or high) and very low levels, it may cause "spokiness" (wave-like deformations) in rolls of motion picture film, cracking of RC prints, cracking of the internal image-receiving layer of Polaroid SX-70 prints, and base-to-emulsion separation in some types of polyester-base films. Very low and/or widely cycling humidity will cause excessive curling of unmounted or unmatted fiber-base prints, especially those on single-weight paper.

Devices for Measuring Relative Humidity

Caretakers of photography collections should acquire an accurate relative humidity indicator so that the actual humidity level can be monitored in storage areas. Ideally, as discussed previously, photographs should be stored in conditions of about 30% RH. However, as will quickly become apparent when a humidity indicator is put into service, such low humidity levels usually cannot be maintained except during winter months in temperate climates. One should try to keep the humidity as constant as possible and in no event permit it to exceed 65–70% for long periods. Various types of humidity-measuring devices are available; they differ in design, accuracy, and price. Suppliers of instruments for measuring relative humidity are given at the end of this chapter.

Taylor 9-inch sling psychrometer (Model No. 1328).

Sling Psychrometers

The sling psychrometer was the first instrument for accurately measuring relative humidity and, when used properly, is still among the most precise. Use of sling psychrometers, however, is rather time-consuming and cumbersome for routine monitoring of relative humidity. They cannot be used for measurements inside of small enclosures such as refrigerators or display cases. Sling psychrometers are satisfactory for calibration of dial hygrometers and other types of mechanical hygrometers.

The sling psychrometer consists of two thermometers mounted on a frame with a handle at one end. Attached to the bulb of one of the thermometers is a cotton wick that is moistened with distilled water before taking a reading. To operate, the handle is gripped in one hand and the thermometer frame is slung around in a circle (hence the name). Moisture in the wet wick (the wet-bulb thermometer) evaporates because of the rapid air motion occurring during rotation of the device, cooling it to a lower temperature. The lower the humidity, the faster the evaporation and the lower the reading of the wet-bulb thermometer.

Use of a Sling Psychrometer

1. Be very careful when using a sling psychrometer in the vicinity of photographs or other valuable objects, because small drops of water are usually ejected from the moistened wick, especially during the initial period of rotation. The droplets of water can travel across a room 10 feet or more! Do not operate a sling psychrometer in a room containing uncovered photographs on tables or hanging on walls.

2. Thoroughly saturate the wick with water before each reading is made. Moisten the wick only with distilled water; dissolved solids usually present in tap water will adversely affect the accuracy of the instrument. The wick should be replaced should it appear dirty or become stiff.

3. After about 2 minutes of rapid rotation, immediately take a reading from the wet-bulb thermometer. At low relative humidities (e.g., 20–40%), rotation times of up to 5 minutes will be required to fully depress the wet-bulb reading.

4. Repeat the operation (with the wick remoistened each time) until two or more wet-bulb readings agree at the lowest temperature obtainable. Then compare the wet-bulb and dry-bulb temperature readings with a psychrometric table (normally supplied with a sling psychrometer) and determine the relative humidity. Psychrometric tables that have a separate entry for *each degree* of wet- and dry-bulb temperatures are easier to read accurately than are psychrometric charts.

A sling psychrometer may have limited accuracy when the relative humidity is below about 25%. At high humidities, sling psychrometers are usually quite accurate. At low temperatures, when the wet-bulb temperature drops below freezing (32°F [0°C]), readings are highly uncertain.

Thermometers in a sling psychrometer should be accurate, but much more important than their absolute accuracy is the requirement that both thermometers agree with *each other*. This can easily be checked by removing the cotton wick from the wet-bulb thermometer (if the wick was wet and moisture remains on the thermometer, it should be removed with a clean paper towel) and allowing both thermometers to stabilize at the ambient room temperature. A discrepancy greater than ¼°F (⅛°C) is unacceptable and the unit should be replaced. A 1°F (½°C) discrepancy between the thermometers will result in a 4% error in the indicated relative humidity.

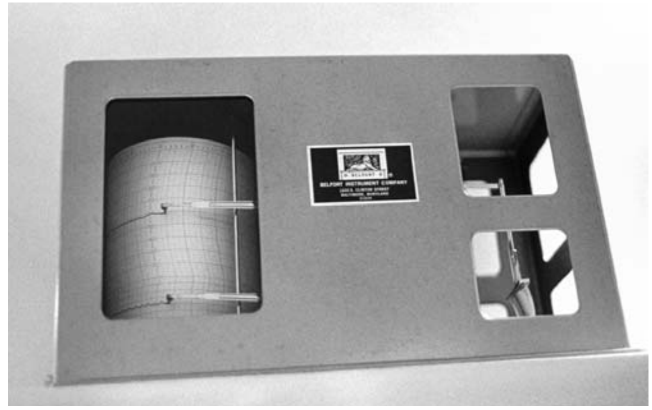
The thermometers must be read carefully — and immediately — after it is certain that the sling psychrometer has been rotated long enough for the wet-bulb thermometer to become fully depressed. An error of ± 1°F (½°C) in reading the wet-bulb thermometer can result in a ± 4% error (high or low) in indicated relative humidity — a range of 8%! If errors are made in reading *both* thermometers, the error in indicated RH may be correspondingly greater. But an accurate instrument operated with care can be expected to produce consistent and reasonably accurate results.

The Assmann psychrometer[9] is a precision instrument operating on the general principles of the sling psychrometer; instead of being whirled in a circle, the Assmann psychrometer has a spring-wound fan to circulate air over the wet-bulb thermometer for up to 8 minutes (at least 5 minutes is recommended). Equipped with individually calibrated mercury thermometers (with a corrected accuracy of better than ± 0.1°C) and infrared radiation shields, Assmann psychrometers cost $350 or more.

Also available are low-cost psychrometers, based on the Assmann design, which have small battery-powered fans to draw air across the wet-bulb thermometer. One model tested by this author, the Psychro-Dyne sold by Environmental Tectonics Corporation (the Psychro-Dyne is similar in most respects to the Belfort Psychron), proved to be reasonably accurate when the relative humidity was above about 40% and when the unit was allowed to operate for several minutes to achieve full depression of the wet-bulb temperature. In this author's judgment, a sling psychrometer such as the 9-inch model made by Taylor Instruments (Catalog No. 1328) is a more accurate instrument and also costs only $65, roughly half as much as the Psycho-Dyne.

June 1983

An Abbeon HTAB-176 dial hygrometer, costing about $135, is shown here in a frost-free refrigerator. When properly calibrated using the procedures outlined in the text, these devices give an accurate indication of relative humidity.



November 1986

A Belfort recording thermohygrograph in the photograph storage room at the Museum of Modern Art. These units, which cost between $500 and $1,000, typically provide a week-long paper chart with a continuous record of relative humidity and temperature.

Dial Hygrometers

The dial hygrometer gives a continuous direct reading of relative humidity at a glance. If carefully calibrated about every 6 months, the better-quality dial hygrometers are accurate within approximately ± 3% over a range between 20% and 90% RH; if the relative humidity in the location where the instrument will be operating is close to that of the calibration point, the accuracy of a dial hygrometer can be ± 1%. Most dial hygrometers are reliable over a fairly wide temperature range.

It is especially important to calibrate a new dial hygrometer *before* it is put into service. Manufacturers' claims to the contrary, this author's experience is that most hygrometers are in poor calibration by the time they are delivered. Good-quality dial hygrometers have a small calibration screw, accessible from outside the case, which allows the dial to be adjusted.

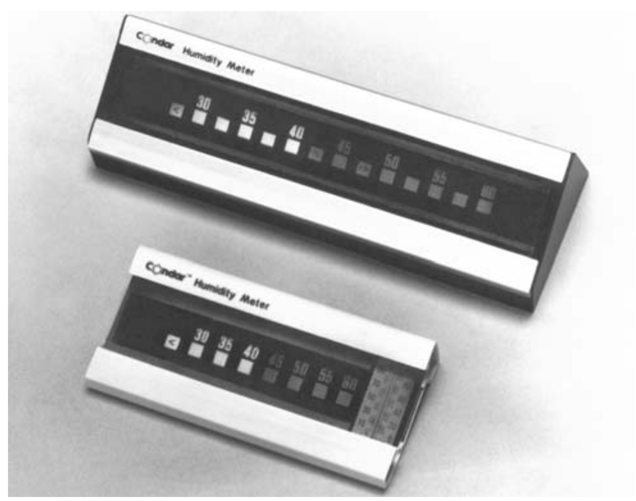
Although dial hygrometers have a relatively slow response time and, depending on air movement, may require 20 minutes or more to stabilize following an abrupt change in humidity, the rate of response is adequate for most photographic storage applications. The humidity-sensing element of some high-quality dial hygrometers is made of bundled human hair. The hair bundle, one end of which is connected to the dial indicator mechanism, changes in length as a function of the ambient relative humidity. Other good-quality dial hygrometers, such as the popular Abbeon Certified Hygrometers (made by the German firm of G. Lufft Metalabarometerfabrik GmbH and sold under many different brand names in the U.S.), utilize bundles of synthetic fibers instead of hair as the humidity-sensing elements.

The Abbeon Model No. HTAB-176, which has a built-in thermometer and costs about $135, is recommended by this author for monitoring most photographic storage environments, including the inside of frost-free, low-humidity refrigerators. The calibration of the unit should be checked every few months with a sling psychrometer, or with the very accurate saturated-salt procedure described later in this chapter.

Low-cost dial hygrometers, such as those with paper sensing elements and sold in hardware stores for $10 or less, can provide very approximate measurements of relative humidity, but often they will be nonlinear and inaccurate by 20% or more, especially in the low and high ranges of the scale.

Recording Thermohygrographs

Recording hygrometers (hygrographs) make a continuous paper chart of the ambient relative humidity for a week or longer periods. When equipped with a recording thermometer, which is usually the case, they are called recording thermohygrographs. Some types make disk charts;



A Condar Humidity Meter. These inexpensive units, which regrettably are no longer available, are based on the principle that certain chemical compounds undergo reversible changes in their crystal structure at specific relative humidities, resulting in abrupt changes in the reflection of polarized light. The "bright" square farthest to the right registers the relative humidity. Condar hygrometers do not drift over time and do not require periodic calibration. In fact, the units are accurate enough to be suitable for calibrating other types of hygrometers. Manufacture of Condar hygrometers ceased in 1987.

Table 16.2 Relative Humidity of Air over a Saturated Sodium Dichromate Solution

Temperature	Relative Humidity
68°F (20°C)	55.2%
70°F (21°C)	54.9%
77°F (25°C)	53.8%

Adapted from: Arnold Wexler and Saburo Hasegawa, "Relative Humidity-Temperature Relationships of Some Saturated Salt Solutions in the Temperature Range 0° to 50°C," *Journal of Research of the National Bureau of Standards,* Vol. 53, No. 1, July 1954, pp. 19–25.

others produce linear graphs. Recording thermohygrographs are fairly expensive — usually costing from $500 to more than $1,000. Most thermohygrographs have humidity-sensing elements of bundled human hair or synthetic fibers, although various types of electronic recording instruments are also available. As with dial hygrometers, it is *essential* that the calibration of recording hygrometers be checked at least every 6 months.

Thermohygrographs have become a common fixture in most museums; some museum personnel are so devoted to the instruments that the mere fact that conditions are being constantly monitored may in time overshadow the need to correct the widely fluctuating levels of relative humidity usually reported by the graphs. Thermohygrographs are valuable for recording daily temperature and humidity fluctuations caused by changes in air-conditioning levels between days, nights, and weekends. To save energy many buildings operate at higher temperatures during non-working hours in the summer (or at lower temperatures during off-hours in the winter); such temperature variations normally result in significant humidity fluctuations.

Electronic Humidity Indicators

Rapidly responding electronic humidity indicators either operate as self-contained, hand-held units or have a humidity probe connected to an indicator unit or chart recorder by a length of electrical wire. These fairly expensive instruments can be made with different types of humidity sensors — the two most common are a special thin-film capacitor in which electrical capacitance changes as a function of relative humidity (a Pope cell), and a sensor in which electrical resistance varies according to the relative humidity (a Dunmore sensor). Associated electronic circuitry computes the dew point or relative humidity from the capacitance or electrical resistance of the sensing element. The hand-held Humi-Chek electronic hygrometers supplied by Rosemont Analytical, Inc. are particularly recommended; available in several models, the units cost between $500 and $900.[10]

A very accurate — and expensive — type of electronic humidity indicator is the dew-point/frost-point hygrometer, whose photocell optically detects formation of dew (liquid condensation) or frost on a polished plate which is slowly cooled by a thermoelectric cooling unit. The relative humidity is computed by comparing the ambient air temperature and the temperature of the polished plate when condensation (or frost) occurs. Electronic instruments with external probes are particularly helpful for monitoring humidity levels inside a refrigerated storage unit from a remote location. Suppliers of electronic humidity indicators are listed at the end of this chapter.

Humidity Indicator Papers

Paper or other material impregnated with a cobalt salt such as cobalt thiocyanate has the property of progressively changing color from blue to pink as the relative humidity increases through a range from 20% to 80%. One such product, Hydrion Humidicator Paper, is available from Micro Essential Laboratory, Inc.[11] By comparing the color of the paper with a color chart supplied with the product, estimates of relative humidity can be made to within about ± 5% in the humidity range covered by the paper. Not well suited for general humidity monitoring, strips of the low-cost paper do have some unique research applications, such as measuring the relative humidity *inside* a sealed glass slide mount, picture frame, plastic bag, or other closed container. Because the colored salt will contaminate and permanently stain adjacent materials, even migrating through a sheet of paper in only a week or two, these paper indicator strips should *never* be placed in the vicinity of valuable photographs, films, mount boards and mats, etc.

Calibration of Hygrometers

It is vitally important that mechanical and electronic hygrometers be checked when initially put into operation, and then from time to time after that to guarantee their continued accuracy. As Garry Thomson observed in *The Museum Environment:*

> The hair hygrometer in its eight-day recording form, often combined with a temperature recorder, has become a common sight in museums all over the world, and testifies to a growing awareness of the importance of climate control. . . . Because it can so easily slip out of calibration, either through a jolt or by slow drift, so that its readings are no longer true, there must be hundreds of humidity records stored away in museums which are in fact worthless. Ideally the hair hygrometer should have its calibration checked monthly.[12]

A carefully operated sling psychrometer should be adequate for routine calibration of dial and recording hygrometers (as well as common types of electronic hygrometers) for most photographic storage needs, but there are applications where more accurate calibration is desired. While a precise Assmann psychrometer or electronic dew-point hygrometer could provide a standard for calibration, a simple and very accurate method of calibrating a hygrometer is to place the unit in a sealed container made of glass or transparent plastic and containing a tray with a

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Hygrometer calibration with a saturated solution of sodium dichromate. The acrylic case, constructed of $\frac{3}{8}$-inch clear Plexiglas acrylic sheet by this author, measures 12x12x6 inches. The sodium dichromate solution is contained in a glass oven dish resting on the bottom of the case. A removable shelf for the hygrometer is provided in the center. The transparent lid, which rests on a foam plastic gasket, allows the user to determine when the hygrometer indication has stabilized (full equilibration may require 2 or 3 days). After noting the exact plus or minus deviation of the hygrometer from the proper reading, the unit is removed from the case and allowed to equilibrate to ambient conditions. The hygrometer calibration screw is then adjusted by the required amount (adjustment right after removal from the calibration case is difficult because the hygrometer reading will start changing immediately to conform to ambient conditions.)

saturated solution of sodium dichromate or certain other salts in distilled water. At a given temperature, the air above the saturated salt solution has a specific, known relative humidity.[13] If properly carried out, sodium dichromate calibrations can be as accurate as ± 1%.

This method is especially suited to calibrating dial hygrometers (several can be placed in the container at the same time if space allows). In this author's experience, a saturated solution of sodium dichromate is especially appropriate for this application because the 55% relative humidity obtained at 70°F (21°C) — see **Table 16.2** — is close to the average humidity found in many museums. Also, the solution is stable during long-term keeping, with no tendency to form crystals which can gradually climb up the walls of the container above the level of the solution.

For greatest accuracy with this method, the hygrometer should be calibrated as closely as possible to the relative humidity in which it will normally be used. For those few institutions that are able to maintain the relative humidity in the recommended 30–35% range, a saturated solution of magnesium chloride is recommended in place of the sodium dichromate solution. This gives a relative humidity of 33.4% at a temperature of 68°F (20°C). For high-humidity conditions (where photographs should not be stored for long periods!), a saturated solution of sodium chloride gives a relative humidity of 75.5% at 68°F (20°C).

The glass tray or dish holding the solution inside the calibration chamber should have as large a surface area as possible, to aid in rapid equilibration after the chamber has been opened. The solution should be mixed with distilled water, and a sufficient amount of the salt added so that a quantity of the salt crystals remains undissolved at the bottom of the tray, with a layer of clear liquid above the undissolved crystals; several days should be allowed for the solution to become fully saturated. A solution depth of about 1 inch is recommended. The solution should be replaced about every 2 years — or sooner if all the salt crystals become dissolved (because of absorption of moisture from humid air), or if all the clear liquid layer should evaporate due to frequent use (or poor container seal) in conditions of low ambient relative humidity.

Calibrations should be performed in a room with a stable temperature, and, if possible, with a relative humidity close to that inside the chamber. After a hygrometer has been placed in the chamber, at least 6 hours should be allowed for the relative humidity inside the chamber to stabilize; it is good practice to leave the hygrometer in the chamber overnight (assuming the room temperature remains constant) to assure accuracy of the calibration procedure. The hygrometer should be adjusted to the proper humidity *immediately* after it is removed from the chamber. The hygrometer should then be returned to the chamber and allowed to stabilize for a final check of the adjustment. If the relative humidity of the room is significantly higher or lower than that of the chamber, the hygrometer indicator will start to change as soon as the unit is removed from the chamber; this makes proper calibration difficult, and several attempts may be required for accurate adjustment.

This author has found this method of hygrometer calibration to be simple to perform on a routine basis.

It has been suggested that the bundled-hair or synthetic-fiber element of a dial or recording hygrometer be "rejuvenated" every few months by placing a wet cloth around the unit (in order to create a high-humidity environment) for about an hour. After the cloth is removed and the hygrometer has stabilized for 24 hours, the unit is recalibrated. Pending further experience with long-term behavior of these units, this author tentatively recommends that this "rejuvenation" procedure be omitted and that instead the calibration of such hygrometers be checked — and adjusted if necessary — every few months with the units in their normal operating environment.

Methods of Controlling Relative Humidity and Temperature in Photographic Storage Areas

While it is recognized that many smaller museums — and the majority of photographers — will not be able to justify the cost of equipment necessary to maintain relative humidity in the 20–30% range throughout the year, an effort should be made to keep the relative humidity as close to this ideal as is practical, and conditions which cause widely fluctuating humidity should be avoided. There are several types of equipment available to meet different needs and budget limitations.

Home Refrigeration-Type Dehumidifiers

Common electric refrigeration-type home dehumidifiers are capable of maintaining *reasonable* humidity levels in room-size storage areas. These units are available from a number of manufacturers and usually cost between $175 and $400, depending on dehumidification capacity (given as "pints of water removed each 24 hours," according to the test method in *ANSI B-149-1*), types of controls, and other features. The more expensive units have built-in humidistats which turn the unit on if the humidity rises above a pre-set level.

The calibration of dehumidifier humidistats should always be checked with an accurate hygrometer since the factory markings are normally inaccurate. Several dehumidifiers may be needed to control the relative humidity in a medium- or large-size room. The capacity of a dehumidifier needed to control a specific room will depend on such factors as the ventilation of the room (if any), moisture introduced through walls and floors such as in a basement, the size of the room, frequency and duration of door openings, number of people in the room, etc. Checking the humidity level of the room under various conditions will indicate whether the dehumidifier has sufficient capacity.

Home dehumidifiers usually have a container to collect water extracted from the air. Most models automatically stop if the container becomes full, but if this cut-off switch should fail, the unit will continue to operate, causing water to spill over the sides of the container and onto the floor. Because of this hazard, it is essential that photographs stored in a room with a dehumidifier be placed on shelves or in cabinets at least several inches above the floor. Dehumidifiers usually have a provision for attaching a hose from the unit to a drain (keep in mind that the hose may become clogged, which may also result in flooding). It is, of course, best to work out some sort of permanent drain arrangement so that the unit will not have to be emptied frequently and so that the dehumidifier will not shut off because the water container is full. In an upstairs room of a house where no water drain is available, a length of garden hose can be passed through the center of a wall and attached to a ground-level or basement drain.

An air conditioner and dehumidifier together can effectively maintain reasonable levels of temperature and relative humidity. The air conditioner will remove some moisture from the air in the process of lowering the temperature. The dehumidifier will remove additional moisture and also prevent excessive humidity levels on cool days when the air conditioner is not operating. In condensing moisture from the air, the compressor motor gives off additional heat, causing the compressor to operate for longer periods than would otherwise be the case; this further reduces the level of relative humidity in the room. Care must be taken to be sure that the air conditioner does not shut off in a room containing a dehumidifier; without the cooling of the air conditioner, the room temperature can rise quickly. Most dehumidifiers will become clogged with ice if the room temperature drops below about 65°F (18.3°C), so the air conditioner should be adjusted not to cool below this temperature.

Forced-air exhaust — and provision for replacement air — in a storage area for photographs is not usually necessary unless people are working in the room for a significant amount of time. Remember that the more moist air that is brought into the room, the more dehumidification capacity will be required.

Home refrigeration-type dehumidifiers remove moisture by passing room air over refrigerated coils which are at a temperature not much above the freezing point of water. Moisture is condensed on the coils because the temperature of the coils is below the dew point of the air. After passing over the cool coils, the air is reheated by blowing it over the warm coils connected to the high-pressure side of the compressor. A dehumidifier is similar in design to a small air conditioner except that, unlike an air conditioner, the hot air is not exhausted outdoors. The net effect of a dehumidifier is to lower the relative humidity and — because of heat generated by the compressor motor — raise the temperature of a room.

Dehumidifiers are especially helpful in tropical areas for preventing the relative humidity from exceeding 65–70%, the level at which fungus may begin to grow on film and print emulsions. Many tropical regions experience sustained periods of very high humidity; at the research station that Eastman Kodak once operated in the tropics of Panama, it was reported that daily humidity levels varied between 63% and 100% during the wet season.[14]

Standard Window Air Conditioners and Special Humidity-Control Models

As previously discussed (**Figures 16.3** and **16.4**), because most air conditioners lower the temperature of air at the same time they remove moisture, the net result is not always a decrease in the relative humidity in a room or building. In fact, when operated during moderately cool days and nights, and under some other common conditions, an air conditioner can actually cause indoor relative humidity to *rise*. Air conditioners dehumidify most effectively not only when it is warm outdoors but also when significant additional heat is generated indoors by lights, people, electrical office equipment, etc. Such conditions increase the operating time of air conditioners, which in turn increases the amount of moisture removed from the indoor air.

Air conditioners that have an "energy saver" switch that turns the fan on only when the cooling compressor is operating generally produce lower relative humidity in a room than do conventional models in which the fan operates all the time (unless the entire unit is turned off). Air conditioners with this feature are preferred for photographic storage areas (they also cost somewhat less to operate).

Some window air conditioners have provision for dehumidifying air *without* cooling and are excellent for temperature and humidity control in photograph storage areas. This type of air conditioner can be identified by a separate humidity-control knob located near the temperature control on the switch panel; in the U.S., several models with independent dehumidifying capability are available from Sears Roebuck and Co.[15] These air conditioners are able to dehumidify air without cooling by switching half of the evaporator coil to the condenser side of the compressor — and half of the condenser coil to the evaporator side of the compressor. Thus, the unit blows cold dehumidified air and warm air into the room at the same time, resulting in the air being at normal room temperature. When these air conditioners operate in the cooling mode, an electric valve in the refrigerant lines switches the coils back to the normal cooling function.

People are sometimes confused about the names identifying the hot and cold coils of an air conditioner. The cold coil is known as the "evaporator" coil even though it *condenses* moisture from the air on the cold surfaces of the coil. The name "evaporator" comes from the fact that the compressed refrigerant (Freon gas) evaporates, or decompresses, in this coil, thus cooling it. The hot coil is known as the "condenser" coil; when Freon in the gaseous state is pumped into the coil by the compressor under sufficient pressure to cause it to become a liquid, considerable heat is given off in the process.

Window-size heat pumps ("reversible" air conditioners) are sold mainly in the warmer southern states for installation in houses without central heating systems. A heat pump operating in its heating mode will not remove moisture from the air, although the relative humidity will usually be lowered by the heating effect.

Keep in mind that most air conditioners cannot operate at room temperatures below about 65°F (18.3°C). At cooler temperatures the cooling coils will become blocked with ice. An exception to this is the type of air conditioner equipped with a water- or brine-filled heat exchanger of the kind usually found in gas-powered units and "chilled water systems" in many office buildings, museums, and other large buildings. These units can be set for a room temperature below 65°F (18.3°C); however, the relative humidity will probably rise to excessive levels without auxiliary dehumidification equipment.

The minimum relative humidity that theoretically can be obtained by air-conditioning systems that do not form ice on the evaporator coils is about 35% with a room temperature of 70°F (21°C). In practice, this low level probably cannot be reached except in very dry climates such as the elevated southwestern parts of the U.S. Minimum obtainable levels of 50–60% RH are more common. To maintain low relative humidities at low temperatures, a desiccation dehumidifier or a "freeze and heat-defrost" system such as that in a frost-free refrigerator/freezer is needed. A brine-spray system to melt ice on cooling coils should *never* be used in an air conditioner that cools storage areas for photographs because significant quantities of spray chemicals may be carried over into the air stream and contaminate the photographs.

Remote Air Conditioners for Individual Rooms

Standard window air conditioners cannot be operated in rooms which do not have an outside wall. Even when window space is available, many people do not like the appearance of an air conditioner unit sitting in the bottom half of a window. In a central air-conditioning system, the condenser coil and the compressor are located outdoors. Central air-conditioning systems, however, are difficult to install in buildings that do not already have duct-work in place as part of the air-heating system. In such situations a small "remote" air conditioner may be needed. This type of unit has an outdoor compressor-condenser unit connected to an indoor evaporator-blower by a length of refrigerant tubing. It is similar in concept to a large central air conditioner except that the indoor evaporator unit is designed to be mounted on a wall and has its own blower and air filter attached.

Several sizes of these remote air conditioners are manufactured under the name Comfort-Aire Twin Pac Remote Air Conditioning System.[16] The indoor and outdoor units may be separated by up to 19 feet of tubing (8 feet is supplied, and an additional 11 feet may be purchased as an accessory). The units are available in 6,000-Btu/hr, 10,500-Btu/hr, and 15,500-Btu/hr capacities. A hole 2½ inches in diameter must be cut in the wall for the refrigerant and electrical lines to pass through. A hose attached to the indoor evaporator unit carries condensed water to the equipment outdoors. If the indoor unit is in a building at a level lower than the outdoor condenser unit, provision must be made to drain condensed water away from the indoor section to a floor drain; a home basement installation may require the indoor unit to be lower than the outdoor section. The refrigerant lines on these remote air conditioners are of the pre-charged, quick-connect type, enabling anyone with a few hand tools to install the units without professional help.

Air-Conditioning and Dehumidification Systems for Large Buildings

Air-conditioning systems in large buildings function on the same general principles as the previously described home units; both ducted-air and chilled-water systems are common. With a piping system that runs throughout a building, a chilled-water system circulates refrigerated water to thermostatically controlled cooling units which regulate the temperature in individual rooms or in larger areas.

Most large air-conditioning systems have no provision for separately controlling temperature and humidity and are unable to adequately reduce the humidity during cool and moist days of spring and fall in temperate climates; humidity control also usually fails during cool nighttime hours in hot climates. Modern systems usually have a fairly high air exchange (exhausting indoor air and bringing in fresh outdoor air) to keep concentrations of cigarette smoke and other indoor pollutants from becoming too high, but this makes humidity control more difficult and wastes a great amount of electricity. Air exchange rates can be reduced substantially if smoking is prohibited.

Humidity control can be improved if provision is made to reheat the cooled air so that the air conditioner continues to operate on cool days without significantly cooling the building. This procedure requires additional energy. New installations for museums and archives should have separate dehumidification equipment for dehumidifying without cooling. Older equipment can be modified to perform this function. A qualified air-conditioning and heating engineer should be consulted for advice on selecting equipment and the best approach to the particular problems of each situation. The engineer should be informed of the need for *constant* year-round humidity control.

Museums with different types of collections may require different levels of relative humidity in various parts of the building. For example, recommended humidity levels for leather-bound books are significantly higher than the ideal 30% for photographs. If a collection requires a specific relative humidity (and temperature), it may be possible to place it in a separate room or area controlled by auxiliary equipment. The Ohio Historical Society stores microfilm in an isolated area. Such an isolated-area system has been described by Amdur,[17] who suggests that rooms for specialized storage not have any walls, floors, or ceilings along the outside of the building. This will allow the existing air-conditioning and heating system in the building to control seasonal temperature extremes and to provide a first stage of humidity control. Auxiliary equipment for isolated storage areas can draw air from the interior of the building; such equipment need have only minimum capacity. Descriptions and engineering data for various types of air-conditioning and filtration systems appear in publications of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE).[18]

As noted in Chapter 19, frost-free refrigerators offer an excellent way to store color materials at low temperatures and low relative humidities. From an economic point of view, it may be less expensive for a museum to purchase a number of frost-free refrigerators than to construct a low-temperature/low-humidity storage vault. The refrigerators may be acquired one at a time if budgets do not permit a large capital expenditure. For example, about one million 35mm color slides could be accommodated in 40 medium-size refrigerators costing about $18,000 at $450 per unit. (Be aware, however, that large prints cannot be accommodated in a refrigerator.)

Bags or Cans of Silica Gel: a Generally Unsatisfactory Method of Humidity Control

Desiccants are substances which, when dehydrated ("activated"), are highly hygroscopic and have a great affinity for moisture in the air. Activated silica gel is the most common desiccant; anhydrous calcium, commercially available under the Drierite name, is also popular.

When drying or storing photographs with desiccants, great care must be taken to prevent small particles of the desiccant from contaminating films or prints. Calcium chloride, sometimes used as a desiccant, is not suitable for photographic applications because it is very prone to producing dust, liquefies when moist, and is corrosive.

The simplest form of desiccant air dryer is a porous cloth bag filled with silica gel. This is placed in a closed container along with the film or whatever is to be dried. If the silica gel has been "activated" by heating to dehydrate it prior to use, it will absorb nearly all the water in the air (regardless of ambient temperature), lowering the relative humidity of air to *less than 4%*, which is substantially below the safe minimum suggested for photographs.

A widely sold air dryer is the Grace Davison Silica Gel Air-Dryer.[19] This device, a perforated aluminum can containing silica gel, has a blue indicator (probably cobalt chloride crystals), visible through a small window on the top of the can, which turns pink when the silica gel has absorbed a significant amount of water vapor. The Grace Davison Air-Dryer can be reactivated when saturated by placing it in an oven at about 350°F (175°C) for several hours and then letting it cool in a small closed container to prevent moisture absorption during cooling. Because small particles of silica gel can fall through the can perforations and contaminate photographs, this device is not recommended.

Small packets of silica gel are packed with cameras at the factory to minimize the possibility of moisture damage during shipment and storage. However, once silica gel has absorbed enough moisture to reach equilibrium with the surrounding air, it will not absorb additional moisture unless the humidity of the air rises. Small quantities of silica gel have only a limited capacity to absorb moisture.

Because of the problems associated with silica gel, and the difficulty of accurately controlling the final moisture content of materials being desiccated, this author does not recommend the routine use of cans or packets of silica gel for maintaining low levels of humidity where photographs are being stored. They can, however, be helpful when no other means of humidity control are available or when very low moisture levels in sealed containers are desired (such as might be the case when storing daguerreotypes). Remember that unless the photographs and silica gel are sealed in a true vapor-proof container — a cardboard box or a file drawer is *not* vapor-proof — the silica gel will continue to absorb moisture from the air until it no longer offers any practical control over relative humidity. Under some conditions, silica gel can lose its ability to absorb additional moisture in less than an hour.

Pre-conditioned in air of a specific relative humidity, silica gel can serve as a "buffer" to help maintain a given humidity level in a sealed display case or other reasonably vapor-proof container for short periods of time.[20] A brand of silica gel known as Art-Sorb, made by Fuji-Davison Chemical Ltd. of Japan and distributed in the U.S. by Conservation Materials, Ltd.,[21] has been advertised as being more effective as a humidity buffer than ordinary silica gel. Also available is a product called Art-Sorb Sheets, which are sheets of polyethylene/polypropylene foam impregnated with Art-Sorb silica gel. The foam-plastic sheets contain about 16% Art-Sorb silica gel by weight and are intended to be cut to size for placement in display cases, shipping crates, etc. Until meaningful test information on the product becomes available, Art-Sorb Sheets are not recommended for use with photographs because of the possibility of harmful emissions from the foam-plastic sheets.[22]

Probably safer are Gore-Tex Silica Tiles, manufactured by W. L. Gore & Associates.[23] The non-dusting 6x6x½-inch tiles are made of moisture-permeable Gore-Tex expanded PTFE (polytetrafluoroethylene) membrane bonded to both sides of an acrylic plastic grid, with silica gel sealed inside.

Continuous High-Volume Dry Desiccant Dehumidifiers

The principle of drying air with a desiccant has been applied on a massive scale in the form of dehumidification machines made by Cargocaire Engineering Corporation[24] and several other firms.

Figure 16.6 shows how a Cargocaire desiccant dehumidifier removes moisture from the air by means of a continuous regeneration cycle for the desiccant wheel, which consists of a lithium chloride-impregnated porous structure. As the wheel slowly turns (approximately 6–20 revolutions per hour), humid air passing through the flutes in the wheel is dried. At the same time, a counterflowing stream of hot air passing through the reactivation sector of the wheel removes the moisture picked up by the desiccant, thus allowing continuous dehumidification. Units with wheels impregnated with molecular sieve and silica gel desiccants are also available for special applications.

The desiccant-impregnated wheel dehumidifier was developed by Carl Munters of Sweden in the 1950's, and manufacturing rights were licensed to Cargocaire in the U.S. and to a number of companies in other countries. The Munters Group of Sollentuna, Sweden now owns Cargocaire and most of the other former licensees.

Desiccation dehumidifiers are extensively employed on ocean ships for maintaining proper relative humidities in steel-walled cargo holds (in which relative humidities would otherwise be around 100%) and in industry for environmental control in areas where such humidity-sensitive items as lithium batteries are manufactured. They are also used to control the humidity in underground storage facilities.

Desiccation dehumidifiers are ideal for controlling relative humidity in storage and display areas for photographs kept at normal room temperature — and for humidity control in entire buildings. The units offer more precise control with less energy expenditure than any other type of dehumidifier, and since they operate independently of heating and cooling equipment, the proper relative humidity can be maintained regardless of seasonal or day-to-night variations in outdoor conditions as well as changes in indoor temperature and moisture loads.

Under normal circumstances the dehumidifiers operate without any desiccant particles entering the air stream. However, it is advised that a HEPA (high-efficiency particulate air) filtration system capable of filtering particles down to a size of 0.3 micron[25] be installed in the output duct of the machine to make certain no liquid droplets or dust can enter the air stream into the storage area, should the desiccant regeneration system and the unit's automatic electrical shut-off controls fail, causing the wheel to become saturated with water. In addition, it is absolutely essential that a separate high-humidity shut-off be installed to cut off *all* electrical power to the dehumidifier, air conditioners, and other equipment in the storage area should the relative humidity rise above a pre-set level. The safety equipment must be periodically tested to be certain that it is functioning properly.

In the past, desiccation air-drying machines were not recommended for controlling the relative humidity in photographic storage areas; contamination was a recurring problem with many of the machines having beds of silica gel open to the air stream. The Cargocaire HoneyCombe machine is claimed by the manufacturer to have eliminated the dust problem.

Cargocaire dehumidifiers are made in a variety of sizes for different applications; some models can remove up to 1,500 pounds of water per hour from the air. The machines can be set to control the relative humidity to any level —

1980

A Cargocaire dry desiccant dehumidifier attached to a color motion picture film storage vault (maintained at 25% RH and 37°F [2.8°C]) at the Library of Congress facility in Landover, Maryland, near Washington, D.C.

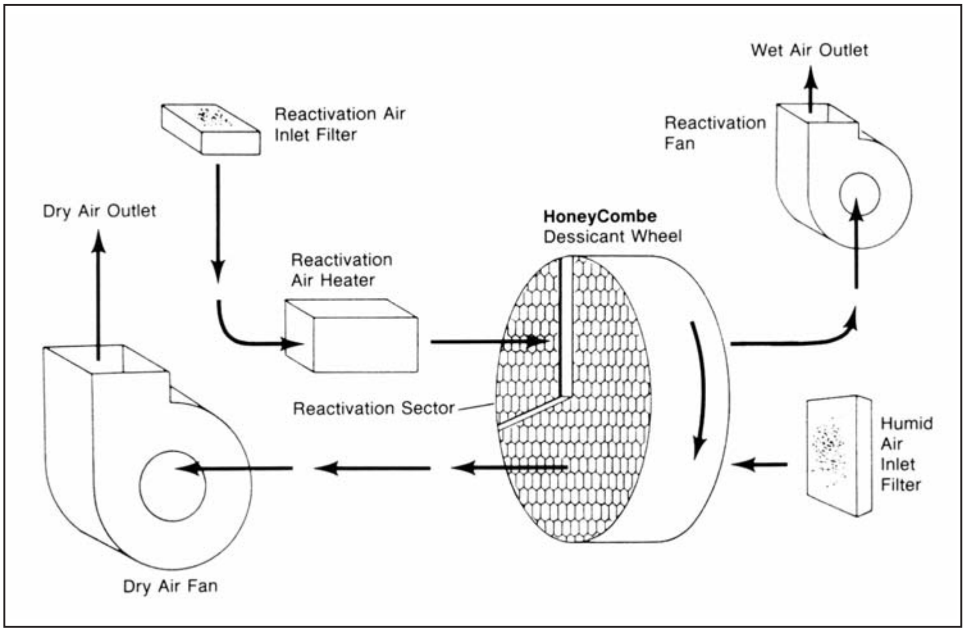


Figure 16.6 Functioning of a Cargocaire dry desiccant dehumidifier.

even as low as 10%. In the larger units, heating is by steam, electricity, or gas; in the smaller units, the reactivation sector is heated electrically. The Cargocaire Model M85-L dehumidifier (about $2,500 including humidistat) has a provision for internally cooling the heated air in the reactivation sector and does not require an outdoor air exhaust; this allows the unit to be located almost anywhere within a building. Cargocaire units in the size range commonly used in photograph cold storage vaults range in price from about $3,500 to $12,000.

Cargocaire offers a special explosion-proof version of its HC-150 dehumidifier that is capable of meeting the building and fire code requirements of most cities and states for electrically powered air-handling equipment which recirculates air in flammable environments. This special unit is recommended for cellulose nitrate film storage vaults.

Continuous desiccant dehumidifiers are currently the only practical and energy-efficient method of maintaining low and precisely controlled humidity at the 0°F (–18°C) or lower temperatures necessary for the long-term storage of most types of color films and prints. Cargocaire units were first used for humidity control of a low-temperature vault for photographic materials at the John Fitzgerald Kennedy Library in Boston, Massachusetts, which opened in 1979.

Cargocaire dehumidifiers are currently in operation in the cold storage facilities at the Warner Bros. movie studio in Burbank, California; Paramount Pictures in Hollywood, California; the Art Institute of Chicago in Chicago, Illinois; the Time Inc. Picture Collection in New York City; the Peabody Museum of Archaeology and Ethnology at Harvard University in Cambridge, Massachusetts; the Library of Congress cold storage facility in Landover, Maryland; the Historic New Orleans Collection, in New Orleans, Louisiana; the National Archives and Records Administration cold storage vaults in Alexandria, Virginia; the Human Studies Film Archive at the Smithsonian Institution in Washington, D.C.; and the Moving Image, Data and Audio Conservation Division of the National Archives of Canada in Ottawa, Ontario. (See Chapter 20 for further information on large-scale cold storage facilities for color materials.)

Reliability Problems Reported with Cargocaire Dehumidifiers — Improved Models Introduced in 1989

A number of institutions using Cargocaire dehumidifiers, including the Art Institute of Chicago and the Peabody Museum of Archaeology and Ethnology, have had serious reliability problems with the units. The most frequent failure has involved the electrical reactivation heaters that drive moisture off the rotating lithium chloride-impregnated wheel. At the Art Institute of Chicago, photography conservator Douglas G. Severson reports that during the first 6 years that the units were in operation (the Art Institute's two cold storage vaults were constructed in 1982), the reactivation heaters in the six Cargocaire dehumidifiers were all replaced at least twice.[26] According to Severson, at one point four of the six dehumidifiers were out of operation. But, in spite of the failures, control of the relative humidity levels in the two vaults was never lost because at least one of the dehumidifiers remained functional while the others were being repaired (the units operate in a redundant manner). Severson says that during the first 6 years of operation, no problems whatever were experienced with the vault refrigeration compressors.

The Art Institute vaults are equipped with fail-safe electrical controls that automatically sound an alarm and cut off electrical power to all cooling and dehumidification equipment should the temperature or relative humidity levels drift beyond pre-set limits. If such a failure should occur, the doors to the vaults would be left closed until the interior reached room temperature (during which time the relative humidity inside the vaults would drop somewhat). The photographs stored inside the vaults would be in no danger should such a shutdown occur. Severson says that the fail-safe shutdown controls are tested regularly.

Cargocaire has acknowledged the problems with the reactivation heaters in the dehumidifiers and several redesigned models were introduced in 1989 which, according to the company, should prove to be far more reliable.

Control of Relative Humidity with Cool-and-Reheat Equipment

Controlling relative humidity in air-conditioned buildings has traditionally been accomplished by heating units — usually electrical — attached to the cool-air ducts coming from the air-conditioning units. The heating units raise the temperature of the air coming from the air conditioners, producing a drop in relative humidity; at the same time, the heaters cause the air conditioners to operate for a longer time without lowering the room temperature below the desired level. Thus, the air conditioners have an increased dehumidification effect on the constantly recirculated air. These systems consume much more energy than desiccant dehumidifiers, and if a low relative humidity is desired — 25% for example — an enormous amount of energy may be required to maintain such a level; with many installations, it will be impossible to reach such a low humidity level even with continuous operation of the cooling and reheating equipment.

When precise regulation at a low level of relative humidity is desired, desiccant dehumidifiers in conjunction with conventional air-conditioning equipment will be much more satisfactory than cool-and-reheat equipment.

Humidifiers to Raise Relative Humidity

To maintain reasonably constant relative humidity in areas where photographs are stored, it will usually be necessary to add moisture to indoor air in the cold periods of the year in temperate climates.

Humidifiers that eject steam or water mists directly into the air should be avoided in any but the most elaborate systems because they can create localized areas of very high relative humidity and, should the controls fail, will raise the room humidity to near 100%. Evaporation humidifiers which are attached directly to home hot-air heating systems, and which have automatic relative humidity controls that can be set by the user, probably present no great danger and will minimize winter/summer variations in humidity. An accurate hygrometer should be placed in storage areas so that conditions can be checked from time to time. Humidity calibrations on home humidifiers are usually inaccurate. Low-cost evaporation humidifiers for the home can be accurately controlled by separate humidistats available from heating equipment supply outlets.[27] This author has employed simple equipment of this type to control the relative humidity in rooms in which accelerated light fading tests are conducted; the humidity can be maintained at ± 5% or better.

Any large-scale humidification system should have "fail-safe" automatic controls to minimize the danger of over-humidification, which could seriously damage photographs in a short time.

When budgets are limited, it almost always best to concentrate available resources on the purchase and operation of *dehumidification* equipment and not be overly concerned about the short periods of the year in cold climates when the humidity may drop below 20%. Generally speaking, high relative humidities are much more harmful to photographs than are low relative humidities.

Prevention of Fungus on Photographs

Fungus growth on photographs can be prevented by keeping the relative humidity in storage and display areas at less than 65%. This simple advice is given with the realization that in many parts of the world, proper control of relative humidity in commercial buildings and homes where photographs are used and stored may be difficult — or, in a practical sense, even impossible. It is important, however, to clearly understand the relationship between relative humidity and fungus growth, and to provide the best storage conditions that one is able.

In museums and archives, it is imperative that adequate humidity-control equipment be provided in storage and display areas. For a collecting institution to ignore this fundamental requirement for the proper care of photographs is a serious irresponsibility.

Fungus, also called "mold" and "mildew," will not grow in temperatures below the freezing point of water, but may thrive in temperatures slightly above freezing, as many people have observed in their refrigerators. Some forms of fungus flourish in temperatures as high as 131°F (55°C). Most forms of fungus will grow in either light or dark situations. Warm and humid conditions are most conducive to fungus growth, but regardless of the temperature, the humidity must be above 65–70% for sustained periods. Wessel has stated: "Generally it is believed that below 70% relative humidity (RH) there is little opportunity for growth. At 80–95 percent RH most forms grow well; above 95 percent RH growth is luxurious."[28] If fungus has started to grow, it can be arrested by drying the photographs and then storing them in low-humidity conditions.

Fungi require nutrients to grow. Gelatin, the major component in the emulsion of films and prints, is, unfortunately, an *excellent* nutrient for fungi. Indeed, susceptibility to fungus attack is one of the serious shortcomings of gelatin-emulsion films and prints that has never been solved. Alternatives for gelatin have been investigated — and have been substituted for gelatin in a few commercial products such as Kodak Velite contact paper which was marketed in the 1950's — but to date none have been developed which are as satisfactory as gelatin in terms of cost, chemical, processing, physical, and optical characteristics.

Fungus spores are found almost everywhere and will grow if the proper combination of nutrients and humidity is present. Fungus growths frequently concentrate around fingerprints on prints and films due to salts in the fingerprints which create localized moist conditions. Fungus growths often damage areas adjacent to the nutrient surfaces on which they are actually growing; they may surface-etch or otherwise damage film base materials. Insects may be attracted to fungus growths, and they or their excrement may do additional damage to photographs.

Hygroscopic glues and print flattener solutions such as Kodak Print Flattener and Pako Pakosol should be particularly avoided in tropical areas because these materials will increase the fungus problem.

Fungi growing on emulsions usually make the gelatin soluble in water. Therefore, water or solutions containing water cannot be used to clean photographs which have been attacked by fungus. Surface fungus can often be at least partially removed by wiping with a soft cotton swab soaked with Kodak Film Cleaner. Slides should be removed from their mounts before cleaning and returned to new mounts after cleaning.

As long as photographs are kept out of obviously damp places such as basements, fungus is not a major problem in most areas of the United States. In tropical areas, which frequently have high average relative humidities, fungus on photographs is common; in rain forests and other particularly humid areas, fungus often causes catastrophic damage to prints and films.

At the first sign of fungus growth (which might be mistaken for dirt in early stages), measures should be taken to reduce the relative humidity in storage locations. As discussed previously, one or more home-type dehumidifiers placed in storage rooms will generally reduce the humidity to a safe level. In severe conditions, such as tropical areas where both heat and moisture are problems, a suitable frost-free refrigerator will provide an excellent humidity-controlled "micro-climate" for storage of both color and black-and-white photographs. Use of these refrigerators is discussed in Chapter 19.

Fungicides

In situations where control of relative humidity is impossible, several methods of preventing fungus from growing on photographs have been suggested. These include processing color negatives and prints with a "washless" system incorporating Konica Super Stabilizer as a final bath (the stabilizer has a long-term fungicidal effect and, used with Konica Color Paper Type SR, Konica Color Paper Professional Type EX, and Konica Color QA Paper, is highly recommended for tropical or other humid areas),[29] postprocessing treatment of films and prints with chemical fungicides,[30] treatment of paper envelopes and interleaving papers with fungicides,[31] laminating prints with pressure-sensitive plastic laminates,[32] or coating films and prints with 3M Photogard or a waterproof lacquer (3M Photogard is claimed to provide excellent protection against fungus attack; lacquers, however, may provide only limited protection). See Chapter 4 for discussion of pressure-sensitive laminates, Photogard, and lacquers.

Eastman Kodak has recommended immersion in a 1% solution of zinc fluosilicate and air drying without wiping as the only effective fungicidal treatment suitable for *both* color and black-and-white films and prints.[33] Zinc fluosilicate, however, is extremely toxic and may be fatal if ingested in even very dilute solutions; treated films and prints may also be harmful if licked or eaten and should never be stored in areas where children are present. Rohm and Haas Hyamine 1622 has been cited by Eastman Kodak as very effective in preventing fungus growth on black-and-white photographs, but the company has cautioned that it should *never* be applied to color films or prints.[34] Black-and-white photographs treated with Hyamine 1622 should never be interfiled with color films or prints.

In most situations — even in tropical areas — this author does not recommend treating photographs with fungicides. A much better approach is to control the relative humidity in areas where photographic materials are stored. If, however, fungicides are applied, treated prints and films should be separated from untreated materials and clearly marked to indicate what type of fungicide was used. If framed or unframed prints are displayed in rooms without humidity control in tropical or other humid areas, the prints should be covered with a suitable pressure-sensitive plastic laminate (see Chapter 4). Fiber-base prints and Ilford Ilfochrome prints (called Cibachrome, 1963–1991), which have a gelatin anti-curl back-coating, should be laminated on both sides.

At one time, Kodak processing laboratories coated Kodachrome transparencies and Kodacolor 35mm negatives with a film lacquer. This practice was stopped in 1970 for reasons that this author has not been able to determine. Kodak films coated with lacquer often have a slightly iridescent appearance when the emulsion side is viewed at an angle to the light. Kodak film lacquer is said to contain a mild fungicide which is safe when applied to color films. This author does not recommend that photographers try to coat their films with lacquers as it is almost impossible to prevent small dust particles from becoming embedded in the lacquer when it is applied; in addition, the dye stability of the films may be impaired.

Edwal Scientific Products Corporation (a division of Falcon Safety Products, Inc.) markets a film-coating product called Permafilm, which the company claims will reduce emulsion scratches, chances of fungus growth, and color dye fading. An Edwal spokesman says the slowing of dye fading is achieved by a reduction of moisture in the emulsion. Edwal has advertised Permafilm as an "almost magic" liquid which, among other things, "makes negatives and movies practically scratch-proof; reduces tearing of sprocket holes." Permafilm definitely does *not* make films scratch-proof, although it may reduce the likelihood of emulsion scratches. This author has no information on the long-term effects of this product on photographs and thus cannot recommend it.

Insect and Rodent Damage to Photographs

If storage areas are kept clean and free from crumbs and other bits of food — and relative humidity and temperature are maintained at moderate levels — damage to films and prints by insects and rodents is not a common problem. However, if mice and rats are able to enter storage areas, they may chew on paper prints or envelopes to obtain small bits of paper for nest construction. Rodents should not be controlled by keeping pet cats in the storage areas because some cats are fond of sharpening their claws on stacks of prints; they can also damage photographs by climbing on stacks of boxes and knocking them to the floor. Any animal can damage photographic materials with its urine and excrement, causing stains and encouraging fungus growth.

Insects may be attracted to photographic materials, particularly in warm, high-humidity conditions or when fungus is present on the photographs. Roudabush has reported some examples of damage to films and mounted slides by carpet beetle (dermestid) larvae. In a few cases the larvae damaged film while it was still inside a camera. Damage to mounted slides was usually restricted to an area of the film no more than 9mm from the edge of the cardboard mount. Experiments showed that the larvae needed to have a grip on the edge of the mount in order to chew on the emulsion. Adult carpet beetles do not normally damage photographs. To eliminate infestations of carpet beetle larvae, Roudabush advised:

> Remove all of the transparencies and fumigate the boxes or drawers of slide files with paradichlorobenzene moth crystals. Naphthalene crystals should not be used. With the slides removed and the slide files closed, the paradichlorobenzene crystals should be left in position for several days so that any emerging larvae will be killed. The slides should be dusted with a soft brush or jet of air to remove any eggs or larvae before replacing them in the storage box. Since the vapor of paradichlorobenzene may seriously damage the transparencies by weakening the cardboard base or support, all of the crystals should be shaken out of the slide drawers and the drawers aired before the transparencies are refiled. Tests to date indicate that transparencies will not be damaged if paradichlorobenzene crystals or concentrated vapor from the crystals are not allowed to contact them. It is also recommended that the treatment be repeated periodically and that stored slides be examined regularly for any evidence of damage.[35]

Wessel has listed a number of insects which may attack paper prints, mounting materials, and envelopes: silverfish, cockroaches, bookworms, and termites.[36] Termite damage is often a by-product of the termites' eating of wood or other materials in the same area as the paper. Insects and rodents may be attracted to glues and pastes, especially in high-humidity conditions.

All photographs on long-term display should be framed under glass to protect them from flying insects, such as houseflies, which may land on them and leave deposits of excrement and dirt. Low temperatures and low relative humidities discourage most insects. Keeping storage areas free of dust, lint, and food particles or wrappings (such as candy bar wrappers) will minimize the possibility of insects inhabiting the areas. New photographs from outside sources should be closely examined for insects before they are added to existing collections.

If, in spite of good housekeeping and proper temperature and relative humidity control in storage areas, insect infestations persist and an insecticide must be used, Bard and Kopperl of Eastman Kodak have recommended sulfuryl fluoride as the only fumigant satisfactory for treating photographs (both color and black-and-white).[37] Sulfuryl fluoride, sold under the trade name Vikane, is reported to be effective against "cockroaches, termites, silverfish, ants, spiders, bedbugs, clothes moths, and carpet beetles, but *not* on microorganisms and mold [fungus]. Vikane is not effective against insect eggs, and some authorities recommend a second application 20 days to one year after the first, depending on the species of the insect."[38] Like all insecticides, sulfuryl fluoride is toxic if excessive amounts are inhaled or ingested; the recommended maximum level of exposure is 5 ppm. Exposure to excessive levels of sulfuryl fluoride "causes abdominal pains, nausea, vomiting, convulsions, chemical pneumonia, lung and kidney damage, and teeth and bone defects."[39] For advice on the safe application of sulfuryl fluoride and fungicides to photographs, Eastman Kodak Company should be consulted.[40]

Air Pollutants

Photographs of all types can be adversely affected by air pollutants. The delicate silver images of black-and-white photographs in general — and RC prints and microfilms in particular — are susceptible to low levels of pollutants such as sulfur dioxide, nitrogen oxides, hydrogen sulfide, peroxides, ammonia, formaldehyde, ozone, and paint fumes. Kodak states:

> The severity of attack by various gases in the atmosphere depends on the concentration of the gases, or fumes, on the presence of residual processing chemicals in the materials, and on the levels of temperature and relative humidity. If there are residual chemicals present, moisture alone may precipitate their attack on an image. Since the effects of oxidation on a silver image are similar, regardless of the cause, it is difficult to determine in any particular case to what extent atmospheric conditions were responsible for the deterioration. In most cases there is no single cause of fading and staining of material; the effect is usually due to a combination of several factors.[41]

Fumes from fresh oil-base paints are a potent source of oxidizing gases which can — in only a few days — cause severe fading and discoloration of black-and-white photographs. To be safe, photographs should be removed from freshly painted rooms for at least 6 weeks if an oil-base paint was applied. Tests conducted by Eastman Kodak in which black-and-white fiber-base and RC test prints were placed in a room 5 hours after painting showed that even very low concentrations of oil-base paint fumes were sufficient to cause image discoloration:

> This painted-room test did substantiate laboratory findings in that certain test prints on both fiber-base and resin-coated papers discolored within 7 days. Also, other test prints discolored when placed in the room up to four weeks after painting was completed. Total oxidant concentrations in the painted room never exceeded 30 parts per billion.[42]

The Kodak study determined that hydrogen peroxide is released by oil-base paints in the course of drying, or autoxidative polymerization. Certain types of cosmetics, such as hair sprays, were also said to produce image discoloration. There is substantial evidence that RC prints are in general more susceptible to discoloration and fading

Table 16.3 National Institute of Standards and Technology Recommendations for Environmental Conditions for Storage of Paper-Based Archival Materials [Not Necessarily Including Photographic Materials]

Prepared for the National Archives and Records Administration in 1983

Category of Storage Conditions	1.	2.	3.
Public Access	yes	no	no
Duration of Storage	short[a]-long	short[a]-long	long[b]
Frequency of access	often	often	seldom
Temperature Range	65–75°F (18–24°C)	50–55°F (10–13°C)	–20°F (–29°C)
Temperature Control[c]	±2°F (±1°C)	±1°F (±0.5°C)	±2°F (±1°C)
Relative Humidity Range	40–45%	35%	—
Relative Humidity Control[d]	±5%	±3%	—
Gaseous Contaminants			
SO_2	<1 $\mu g/m^3$	<1$\mu g/m^3$	<1$\mu g/m^3$
NO_x	<5 $\mu g/m^3$	<5 $\mu g/m^3$	<5 $\mu g/m^3$
O_3	<25 $\mu g/m^3$	<25 $\mu g/m^3$	<25 $\mu g/m^3$
CO_2	<4.5 g/m^3	<4.5 g/m^3	<4.5 g/m^3
HCl Acetic Acid HCHO (formaldehyde)	use best control technology	use best control technology	use best control technology
Fine Particles			
TSP[e]	<75 $\mu g/m^3$	<75 $\mu g/m^3$	<75 $\mu g/m^3$
Metallic Fumes	use best control technology	use best control technology	use best control technology

a) Short-term storage is defined in this table as a wide range of time of storage. Documents may be removed and replaced daily or stored for many years depending on requests for their use.
b) Long-term storage is defined in this table as a time of storage intended to be 50–100 years or more. Documents designated for this type of storage would be those of "intrinsic value" and designated for preservation as long as possible.
c) Temperature should be in the given range and should not vary more than these control values.
d) Relative humidity should be in the given range and not vary more than these control values.
e) Total suspended particulates: the weight of particulates suspended in a unit volume of air when collected by a high-volume air sampler.

Note: It may be desirable to provide system capability to achieve lower levels of temperature and relative humidity than the levels given in this table. Some studies tend to indicate that for long-term storage, either or both lower temperature and lower relative humidity may be desirable.

Adapted from: Robert G. Mathey, Thomas K. Faison, Samuel Silberstein, **Air Quality Criteria for Storage of Paper-Based Archival Records**, Center for Building Technology, National Engineering Laboratory, National Institute of Standards and Technology (formerly known as the National Bureau of Standards), Gaithersburg, Maryland, November 1983, p. 22.

October 1992

Air purification, dehumidification, and refrigeration equipment at the Warner Bros. motion picture archive on the Warner Bros. studio lot in Burbank, California. This multi-million dollar humidity-controlled cold storage facility, which went into operation at the end of 1992, employs a sophisticated computer-controlled air-quality management system to remotely monitor the atmosphere in the storage vaults for the presence of acetic acid vapors (which can evolve from acetate film base during long-term storage) and formaldehyde vapors. The redundant, activated-carbon air-filtration system is designed to remove these gases as well as sulphur dioxide, hydrogen sulfide, peroxides, ozone, acidic fumes (e.g., nitrogen oxides), alkaline gases, and ammonia. In keeping with ANSI film storage recommendations, the relative humidity is maintained at 28%. Shown here with some of the air-quality equipment in the high-security facility are John Belknap, Manager of Film Vaults/Assets, and Bill Hartman, Manager of Asset Inventory Management and Research in Corporate Film Video Services at Warner Bros., a division of Time Warner Inc. (See Chapter 9 for further discussion of the Warner Bros. film archive.)

caused by low-level air pollutants and other contaminants than are fiber-base prints. Print lacquers were found to give little protection against airborne contaminants.

Water-base latex paints reportedly do not release oxidants in amounts that could harm silver images. None of the latex paints included in the Kodak study caused discoloration of prints. On the basis of these findings, it is recommended that storage rooms, exhibition areas, and darkrooms be painted exclusively with latex paint.

Maximum levels of pollutants in areas where photographs are stored have not been established; however, maximum concentrations for art museums have been proposed.[43] As a rule, the level of pollutants should be as low as feasible:

> Great care should be taken to eliminate these gaseous impurities from the long-term storage environment because even very small concentrations may cause extreme damage. Suitable means for removal of gaseous impurities are available, such as air washers operating with treated water for elimination of sulfur dioxide, and activated charcoal for the adsorption of sulfur dioxide and hydrogen sulfide. These require consistent control and, in the case of activated charcoal, proper recycling.[44]

At the request of the U.S. National Archives and Records Administration, the National Institute of Standards and Technology (formerly known as the National Bureau of Standards) made a study of the storage conditions in the National Archives facilities in Washington, D.C. and made recommendations for environmental conditions for storage of paper-based records. Summarized in a 1983 report entitled *Air Quality Criteria for Storage of Paper-Based Archival Records*,[45] the study did not specifically address the requirements of photographic materials; nevertheless, the report provides practical guidelines for conditions in an archive or museum (see **Table 16.3**).

Of particular note is the extremely low temperature of –20°F (–29°C) recommended for long-term storage. Intended for "permanent" preservation of even the most inherently unstable paper-based materials, this temperature is far lower than what has generally been advocated in the past for museum and archive storage.

In most storage and display situations, such as in homes and offices, it will not be economically feasible to install equipment for control of pollutants. The best that can be done is to prohibit cigarette smoking, keep exchange of outside air to a minimum (unless cooking is done on the premise, in which case an exhaust fan to the outdoors should be placed above the cooking area), and operate air-conditioning equipment on a 24-hour basis during warm and humid periods. Additional humidity control with home-type dehumidifiers will be of benefit.

Equipment to control airborne pollutants in museums and archives is supplied by Purafil, Inc. (see *Suppliers List* at the end of this chapter) and others. Purafil air filtration equipment is used at the International Museum of Photography at George Eastman House and the Library of Congress, among other institutions.

Treating black-and-white films and prints with a solution of Kodak Rapid Selenium Toner, Kodak Poly-Toner, or Kodak Brown Toner affords substantial protection against common air pollutants. James M. Reilly and co-workers at the Image Permanence Institute recommend a polysulfide treatment for maximum protection of microfilm images.[46]

Beginning in 1993, the National Archives and Records Administration in Washington, D.C., acting on the recommendation of Steven Puglia, a photographic preservation specialist at the Archives, will employ the IPI polysulfide image stabilization treatment for all microfilm and other black-and-white films processed at the institution.

Detection of Harmful Air Pollutants with Agfa-Gevaert Colloidal Silver Test Strips

In 1972, Edith Weyde and associates at Agfa-Gevaert AG in Leverkusen, West Germany published the details of a simple test to determine whether the atmosphere in a storage area contains gases which could harm the silver images of films and paper prints. The method grew out of a project investigating the deterioration of photographs at the Munich Archives. In the 1960's, curators of the Archives had observed brown spots where image silver had been destroyed on prints and films in the collection. Weyde's research into this problem led to the development of colloidal silver test strips:

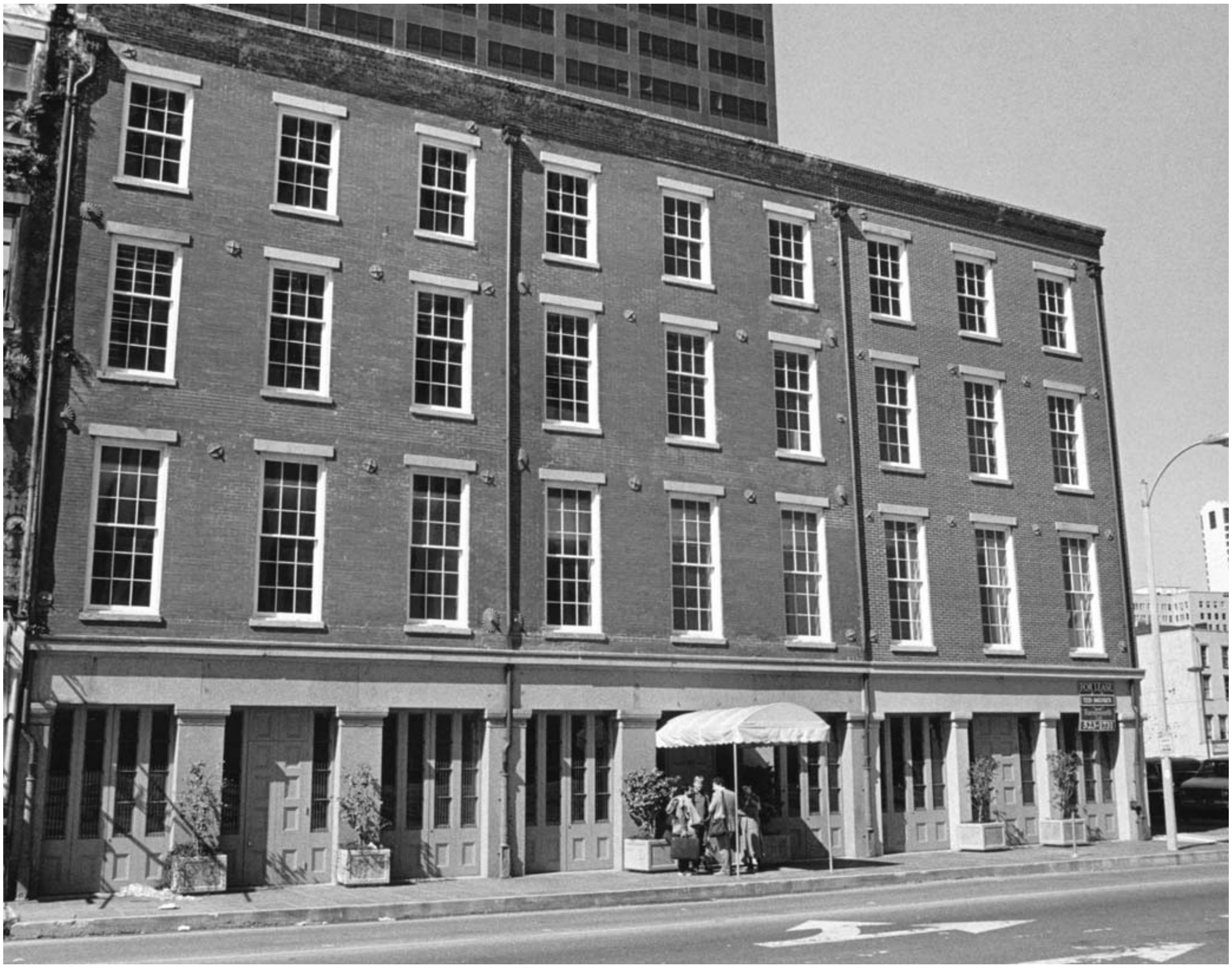
> To detect very small amounts of oxidizing gases, layers of yellow colloidal silver were used which had a grain size of less than 30 nm. These underwent a dark discoloration due to oxidizing gases and only at a very high concentration of the gases did they fade or bleach. This discoloration is due to a change in grain, as shown by electron micrographs. Very fine grains disappear making the average grains coarser.
>
> . . . The colloidal silver layers were superimposed with a lacquer print resembling an Agfa diamond, which protected the silver layer against oxidizing gases. If the air being examined contained oxidizing gases, the area around the diamond darkened which left the symbol light under the lacquer cover.
>
> The concentration of oxidizing gases in air is usually quite small. The darkening of the test layer takes considerable time. We conclude that, where darkening occurs after weeks or a few months, there will be danger for the archival storage of valuable photographic documents. If noticeable darkening occurs only after one or more years, there does not seem to be serious danger for the silver images stored in vaults or archives.[47]

October 1987

An Agfa-Gevaert colloidal silver test slide, matted and in a small metal frame (without glass), in the photograph storage vault at the Art Institute of Chicago.

Weyde, in this important article, went on to describe the two principal applications of the test strips:

> **(a)** Testing for damaging gases given off by a variety of different materials: It has been found that freshly produced plastic packaging or storing materials are very dangerous. Such materials can still be very active, releasing monomer or other compounds used in manufacture, such as polymerization catalysts which are very often peroxides. Of special interest is also the activity of automobile exhaust fumes, which can differ greatly in their composition, depending on a variety of conditions. During the oxidation of hydrocarbons, alkyl radicals are produced which, with oxygen, form peroxide radicals. Additionally these engine exhaust fumes often have an acid reaction, as they contain, among other substances, nitric oxides.
>
> **(b)** Testing the atmospheres of various rooms: Such colloidal layers of silver are intensely discolored in laboratories, garages, and bathrooms. The results varied for rooms with oil and gas heating systems depending on ventilation. . . . In Europe silver images were frequently discolored in photographic shops, particularly in Denmark and Sweden, where the displays were open to the street only. An examination of these localities showed that such shops were usually situated in very narrow streets carrying a volume of traffic, and were often at traffic lights, or near parking lots, and gas stations. In this case the layers of colloidal silver exposed to the air were discolored, often in a matter of weeks.
>
> . . . It was possible to draw the cautious conclusion that color change of the layer of col-



Henry Wilhelm – February 1987

Located on Tchoupitoulas Street in New Orleans, this restored building owned by the Historic New Orleans Collection houses cold storage vaults for black-and-white negatives, color films and prints, and cellulose nitrate negatives. Also in the building are manuscript archives, conservation labs, and administrative offices.

> loidal silver occurred about 10 times earlier than the first visible destruction of a photographic layer of silver. Color change of the layer of colloidal silver occurring after a few weeks or months probably indicates an atmosphere which can cause destruction of the silver layers.

Beginning in the early 1970's, small numbers of the colloidal silver test strips were distributed to several institutions in the U.S. with large photographic collections, including the Library of Congress, the National Archives, and the Mississippi State Archives. The Agfa Corporation has reported that several of the test strips placed in collections showed a very rapid response. Upon investigation the source of the problem in one case proved to be ozone and nitrogen oxides generated by a nearby Xerox copying machine, while at another institution the harmful fumes were being given off by the adhesive from recently installed floor tiles. Electrostatic office copying machines and electronic dust precipitators may generate ozone and nitrogen

Alan B. Newman – February 1987

The control panel for the building-wide fire suppression and intrusion alarm system at the Historic New Orleans Collection.

February 1987

Curator John H. Lawrence is seen here with large cylinders of Haylon gas at the Historic New Orleans Collection in New Orleans, Louisiana. Haylon fire-suppression systems are particularly appropriate for photographic storage areas because, unlike water or other liquid and dry chemical fire extinguishers, Haylon gas does not freeze, leaves no residue, and does not harm photographs, paper, or other fragile materials.

February 1988

The Newberry Library, founded in 1887 in Chicago, is one of the country's leading research libraries. The temperature- and humidity-controlled bookstack building, completed in 1982, is the windowless structure located behind the main library building. Fireproof passageways provide access to each floor from the main library.

oxides; such equipment should not be installed in areas where photographs are stored.

The Agfa-Gevaert colloidal silver test strips are the best means devised to date for monitoring airborne pollutants in areas where photographs are stored in homes, offices, museums, and archives. The test strips are inexpensive and can be placed throughout museums, in storage and display areas, in darkrooms, inside of display cases and frames, and even inside of storage boxes.

After the initial supply of the test strips was exhausted in the early 1970's, they remained unavailable until 1987 when James Reilly, director of the Image Permanence Institute at the Rochester Institute of Technology, persuaded Agfa-Gevaert to resume manufacture of this much-needed item. The test strips may be purchased from the Image Permanence Institute in Rochester, New York.[48]

Control of Dust

Any photographer who has had to spot or retouch magnified dust specks on enlargements from 35mm negatives knows that dust is almost everywhere and that getting rid of it is difficult. Accumulations of dust may contribute to physical damage of print and film emulsions, especially when photographs are stacked in a pile and surface abrasion results from moving them about. Dust-caused scratches on negatives commonly occur when films are slid in and out of plastic or paper enclosures; the dust — sandwiched between the surfaces of the photograph and the enclosure — acts as an abrasive. Reactive dusts can cause localized fading and discoloration on prints and films; a particular danger is the fine dust from dry fixers which may become airborne when the fixer powder is poured into a container for mixing. Unless very well protected, negatives and prints should not be kept in a darkroom for long periods.

Prints and films should be stored in closed containers; with the exception of cellulose nitrate negatives, it is not necessary to ventilate storage boxes and cabinets. In fact, for a number of reasons, ventilation will usually do more harm than good.

Where possible, air filtration systems should be installed in buildings or rooms in which photographs are stored. Electrostatic dust precipitators are not recommended for storage areas because of possible ozone generation which can be very harmful to silver images. Air filtration requirements are given in applicable standards such as *ANSI PH1.48-1982*. A particularly helpful discussion of air filtration equipment has been written by Garry Thomson.[49]

In general the best way to control dust is to practice good housekeeping, to regularly vacuum-clean floors, and

Bonnie Jo Cullison working in the master microfilm negative storage room of the Newberry Library. The relative humidity in this room is maintained at 35%, and the temperature at 60°F (15.6°C). Air in the bookstack building is filtered to remove dust, oxidizing gases, and other airborne pollutants.

to wipe the tops of tables and counters with a damp sponge and carefully dry them with paper towels before use with photographs. Food and smoking should be banned from storage and study areas. Windows leading to storage and display areas should be kept closed at all times; air conditioning usually reduces the amount of dust in the air.

Minimizing the Danger of Fire in Photographic Collections

With irreplaceable collections of photographs that will be kept for hundreds or even thousands of years, the need to prevent fires, or to quickly detect and control them should they occur, cannot be overemphasized. Particularly valuable photographs, such as original camera negatives and preservation release prints from major motion pictures, should be duplicated and the two copies stored in separate geographic locations.

There have been a number of recent fires in major photographic collecting institutions. Most, such as the 1978 fire at the International Museum of Photography at George Eastman House, have been associated with improper storage conditions for cellulose nitrate motion picture films. (For information on the properties and care of cellulose nitrate film, see **Appendix 19.1** at the end of Chapter 19.)

In 1982 there was a fire at the Design Conspiracy Color Lab in Oakland, California which destroyed color negatives and transparencies belonging to a number of well-known photographers, including Stephen Shore, Meridel Rubenstein, Judy Dater, and Richard Misrach. The fire apparently resulted from arson in an adjoining building.

In 1986 the central Los Angeles Public Library, a building that had been cited for fire-safety violations for nearly 20 years, had a major fire that burned out of control for more than 4 hours, injured 46 firefighters, and caused a loss of over $20 million in books alone. None of the photographs in the library's large photography collection were lost in the blaze itself, but the collection suffered extensive water damage.

Whenever possible, noncombustible materials should be used in building construction and in equipping storage and display areas. Smoking should be banned in all museum and archive buildings. Particular attention should be given to electrical wiring, lights, motors, and heating equipment to make certain that they conform to applicable safety codes. Automatic Haylon-gas fire extinguishing systems offer very effective fire control in many types of storage situations. Water sprinkler systems should be avoided; despite their effectiveness in controlling fires, the water spray and resulting flooding may seriously damage or even destroy a photographic collection.

Most fire-resistant cabinets and safes have walls lined with materials that release water vapor when heated; the evaporation of moisture has a cooling effect which minimizes temperature increases inside the enclosure during a fire. However, the released water vapor increases internal relative humidity to the point where photographs may be seriously damaged.

It is beyond the scope of this chapter to thoroughly discuss fire prevention and control measures. The reader should consult applicable publications of the National Fire Protection Association, Inc.[50] Especially helpful are: *Protection of Museums and Museum Collections – 1980*, NFPA Publication No. 911; *Archives and Records Center – 1980*, NFPA Publication No. 232AM; *Protection of Library Collections – 1980*, NFPA Publication No. 910; and *Detecting Fires*, NFPA Publication No. SPP-28. Also recommended is G.W. Underdown's *Practical Fire Precautions*, 2nd edition.[51]

Flood and Water Damage

An unfortunate consequence of a fire is damage caused by the water needed to extinguish the fire. The extensive water damage to the photography collection from the 1986 fire at the Los Angeles Public Library and the more than one million books that suffered water damage in the disastrous 1988 fire in the Soviet Union at the Academy of Sciences Library in Leningrad are examples of this.

Ideally, storage containers should be constructed and housed in such a way that water dripping from above will not enter them; metal or plastic motion picture cans sealed with tape and stored flat are an example. With still photographs, other than making certain that photographs are never stored in boxes directly on floors, there are few practical methods of protecting working collections from water damage should there be a major roof leak, burst water pipe, or flood. Efforts can be more profitably directed at preventing water from entering storage and display areas.

Valuable photographs should not be stored in buildings located in known or potential areas of flooding. The consequences to a photographic collection in a flooded museum have been graphically described in *The Corning Flood: Museum Under Water*.[52] An excellent review of procedures for handling water-soaked photographs has been written by Klaus B. Hendriks and Brian Lesser.[53]

A discussion of flood, earthquake, and other hazards related to museum location can be found in *Facing Geologic and Hydrologic Hazards: Earth-Science Considerations*.[54]

More common sources of water damage than natural floods are leaking roofs, burst water pipes, backed-up sewers in basements, etc. Pipes should not pass through storage areas, and the likely consequences of water leaks from nearby plumbing should be carefully assessed. In general, photographs should be stored neither in basements nor in attics or other rooms located just below the building roof. Basements are subject to flooding from backed-up sewers or water leaks during heavy rains. Even if roofs are very carefully maintained, nearly all of them will eventually develop leaks. If one considers all of the accidents, dripping pipes, and leaking roofs that have occurred in a building over the past 25 years, for example, and then contemplates what *might* be expected to happen during the next 500 or 1000 years, the dangers will become obvious. Unlike books, which are usually printed in large numbers of copies, most photographs are unique and cannot be replaced should they be damaged or destroyed.

Preservation librarian Bonnie Jo Cullison and staff member Patrick Morris examine a book in the bookstack building of the Newberry Library. The public is not permitted to enter the stack areas (specific books and manuscripts are brought out upon request). To minimize fading of book bindings and other light-induced damage, stack areas remain in darkness most of the time, with the overhead lights between the shelves turned on by the staff only when necessary. The building is maintained at 60°F (15.6°C) and 45% RH (± 3%).

February 1988

Building Design and Environmental Control at the Newberry Library in Chicago

Completed in 1982, the 10-story bookstack addition to the Newberry Library in Chicago, Illinois for housing books, maps, manuscripts, and microfilms is an outstanding example of a thoughtfully designed long-term storage facility. The windowless outer walls of the building, including the roof and basement, have a waterproof and fireproof double-shell construction. Each floor is self-contained and isolated from the others; access is by stairways located in two turrets connected to the building, and through a services building which connects the bookstack to the main library. Elevators, water pipes, and principal electrical power distribution wiring are contained in the services building, isolated from the bookstack building.

To eliminate the possibility of water damage resulting from broken pipes or faulty fixtures, there are no water pipes, bathrooms, or fire-suppression sprinklers anywhere in the bookstack building. Large numbers of ionization smoke detectors are located on each floor. The Special Collections Vault is equipped with a Haylon-gas combustion-suppression system. Smoking is not permitted in the building.

Operating and monitoring the temperature, relative humidity, security, and fire detection systems for each floor is a Johnson Controls JC-85-40 computer-controlled building-automation system :

> Electronic sensing devices located on each level of the bookstack building and in the Microtext Masters Storage Room [where microfilms are housed] signal Field Processing Units. These, in turn, report the temperature and RH to the Central Processing Unit (CPU) in the Building Control Systems Room. There, a CRT and printer make it possible to "call up" this information as well as the status of all the individual components of the heating, ventilating, and air-conditioning system at any time.
>
> At periodic intervals, a printout on the status of any of the field data points is run off. Presently the CPU produces a Trend Log for both temperature and RH, storing readings taken at two-hour intervals and printing them out in a specified format every 24 hours. . . .
>
> High- and low-level limits for all the temperature and RH calibration points have been programmed into the system. If these are exceeded, an alarm is activated at the CRT and, when the library is closed, on a pager worn by the security personnel on duty 24 hours a day. This alarm will sound until it has been acknowledged at the CRT, thus ensuring that the condition is responded to by a trained staff member. A print-out of the alarm condition is produced simultaneously.[55]

Under the guidance of Paul Banks, conservator at the library from 1964 until 1981, rigid specifications were established for temperature, relative humidity, and maximum air pollution levels. The temperature is maintained at 60°F (15.6°C) ± 5°F. The relative humidity is kept at 45% (± 3% on a daily basis, or ± 6% seasonally). Relative humidity in the microfilm storage room is 35% RH, in keeping with storage recommendations for silver-gelatin films. The building is equipped with a three-stage air-filtration system: ". . . an initial particle filter; a second-stage chemisorbent filter (Purafil, Inc.) of pelletized activated alumina impregnated with potassium permanganate, capable of absorbing, adsorbing, and chemically oxidizing gases; and a final, high-efficiency (90–95 percent) particle filter."

Writing about the new bookstack building, Bonnie Jo Cullison, preservation librarian at the library, said: "Being able to prolong the useful life of library materials by maintaining a stable environment is terrific; but the current environmental conditions are actually a compromise. If economic and user constraints could be eliminated, it would be ideal to literally freeze most of the library's materials — theoretically extending their lives indefinitely."[56]

Notes and References

1. A Special Committee of the American Association of Museums, **America's Museums: The Belmont Report,** Report to the Federal Council on the Arts and the Humanities, October 1968, p. 57. The source of the quote was "a curator of wide experience" who was not identified by name. The quotation was included in a discussion of conservation and restoration in the "Unmet Needs" chapter of the report.
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