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Environmental Guidelines for the Storage of Paper Records

William K. Wilson

Abstract: This technical report suggests environmental parameters that influence the preservation of paper-based records in libraries and archives. Storage parameters addressed include temperature, relative humidity, exposure to light, gaseous contaminants, and particulates. Values and procedures for the various parameters are recommended. An appendix provides information germane to the development of environmental guidelines for storage with a technical summary of information in the literature. A glossary is included.

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Foreword

This report grew out of work sponsored by NISO to create a national standard to define environmental guidelines for libraries and archives. Agreement could not be reached on the specifics that a standard should address. However, administrators of libraries and archives and environmental engineers continued to request guidance on this topic. This report is an effort to meet that need by providing some insights into the questions that must be examined in planning an appropriate environment for paper records.

Over the last decade many persons contributed to NISO's exploration of this topic and it is appropriate that their contributions to NISO's work be recognized. The following persons served on the original NISO standards committee on Environmental Guidelines: Paul N. Banks, chairperson; Edmund Winslow; Barclay W. Ogden; David H. Stam; Philip A. Knachel; and Mary Lynn Ritzenthaler. This committee was reconstituted in 1988 with the following members: William K. Wilson, chairperson; Alan Calmes; Ernest Conrad; Paul Banks; Margaret Byrnes; Susan Lee-Bechtold; Edwin Parks; Chandru Shahani; Gay Walker; and John Waterhouse. NISO extends to these experts its appreciation and thanks for their contributions and support.

This report was written by William K. Wilson. For fifteen years Wilson was chief of the Paper Section of the National Bureau of Standards (now the National Institute of Standards and Technology). Since his retirement Wilson has been an active contributor to setting national standards for papers for permanent records through the National Archives and the ASTM.

The following persons assisted in the final editing of this report: Ed Brandon, retired chief of the Paper Science Department, Miami University (Ohio); Ed Parks, National Institute of Standards and Technology (retired); David Erhardt, Smithsonian Conservation Laboratory; and Kitty Nicholson, senior conservator, National Archives and Records Administration.

This technical report is the first in the NISO Technical Report Series. It is not a national standard and its material is not normative in nature. Comments may be addressed to: National Information Standards Organization, 4733 Bethesda Avenue, Bethesda, Maryland 20814.

Patricia Harris
Executive Director
National Information Standards Organization

Preface

Paper-based records are the foundation of our recorded history. Most of the records of the past are on paper and, in spite of the fact that many records now are computer-based, most records that are expected to last for many years are on paper. The task of preservation includes papers with different chemical and physical compositions assembled as books, pamphlets, single sheets in folders, letters, and maps. Paper-based records in archives and libraries may range in age from centuries to days. Most of these records, regardless of condition, have survived for only a fraction of their expected lifetime.

Experience and research have shown that maintaining an appropriate storage environment can significantly enhance the long-term preservation of library and archives collections. However, the storage environment in a repository may be chosen for reasons of human comfort or cost, not to achieve the preservation of materials. Thus, many systems capable of maintaining a good preservation environment are modified for human comfort, to run more cost-efficiently, or to shut down when the building is not occupied.

This technical report addresses boundary conditions for temperature, relative humidity, light, airborne particulates, and gaseous contaminants in storage of paper-based records in libraries and archives. The many factors that influence the choice of environmental boundary conditions for a repository include

- financial resources
- geographic location
- facility type (archives, vault, research library, historic house, warehouse)
- document value
- handling frequency (daily, yearly, century)
- retention objectives
- material composition (paper, parchment, photo)
- disaster vulnerability
- pattern of use (exhibit, research, teaching, special showings for visitors)
- construction of building.

However, rigid requirements for environmental conditions in archives and libraries are impossible for the following reasons:

- The control of parameters other than temperature in a building is costly.
- The control of relative humidity is especially problematic, because
  - a building may not be amenable to relative humidity control, and
  - the control of relative humidity in the lower range, because of limitations of air-conditioning equipment, is limited and costly.
- The best environment for paper records is not suitable for people.
- Environmental damage is different for different records in the same building, for example,
  - damage to records that are seldom used differs from
  - damage to records used frequently and exposed to light, such as those in the reference section.

This technical report includes basic information on the effect of the environment on records and makes recommendations for general situations. However, because organizations must make decisions based on the realities of the moment, this report serves as a guide, not as a specification. The emphasis is that the development of an adequate environment for storage of records depends first on the adequacy of the physical characteristics of the building itself.

William K. Wilson

Environmental Guidelines for the Storage of Paper Records

1. Purpose and Scope

1.1 Purpose

The purpose of this technical report is to guide librarians, archivists, engineers, architects, and others involved in the design, construction, renovation, and maintenance of buildings that serve as storage repositories for record collections.

1.2 Scope

This technical report provides guidelines for the environmental parameters that influence the deterioration of paper-based records housed in a storage repository. Specifically, it suggests minimum and/or maximum values for temperature, relative humidity, exposure to light, and the removal of gaseous and particulate contaminants.

The report is designed so that a user may select specific limits for a particular storage condition or repository. The choice of limits will depend in part on (a) local climatic conditions,(b) considerations of human comfort, (c) currently available technology for environmental control systems, (d) constraints of existing buildings, (e) limits of construction materials, and (f) cost considerations.

The recommendations contained in this technical report primarily address the storage of paper records, but they also take into consideration the storage of animal skins (leather, parchment and vellum) and photographic materials which are typically stored in the same space as paper-based records.

The body of this technical report includes technical recommendations for environmental parameters and a summary of the information on which these recommendations are based. Background material used to develop these parameters is based on many reference publications, and some support material was developed especially for this technical report. The rationale for the creation of this technical report appears in the appendix.

2. Storage Parameters for Paper Documents

Storage parameters for paper documents are temperature and relative humidity, exposure to light, gaseous contaminants, and particulates.

2.1 Temperature and Relative Humidity

These conclusions are drawn from a review of the literature:

1. For chemical stability, the lower the temperature where paper is stored, the better.
2. In usage situations, a compromise must be made between people and records.
3. For storage of paper records with only occasional retrieval, a constant temperature within the range from deep-freeze to about 65 °F would be suitable.
4. Fluctuations in temperature increase the degradation rate of paper relative to storage at one temperature (Shahani, Hengemihle, and Weberg 1989).
5. For chemical stability, the lower the relative humidity where paper is stored, the better.
6. For ordinary use, paper may be handled safely around 20% RH. If paper is folded during use, about 30% RH would be safer. It is a matter of degree rather than kind, but maintaining RH at 40-50% for handling is not necessary.
7. To avoid mold growth, paper, leather, and parchment should be stored at an RH lower than about 55%. The literature is not in agreement on this figure; 70% is the value usually given, but lower values have been suggested. To provide a margin of safety, especially as microenvironments tend to vary more than macroenvironments, 55% is suggested.
8. Parchment may safely be stored at 30-50% RH. For stability, 30% is better, but if parchment has been stored at 50-60% relative humidity, changing the relative humidity to 30% might damage the printing.
9. Different photographic materials cover a wide range of RH storage requirements, but all may safely be stored at 30% RH. Literature, standards, and current practice give a range of recommendations for temperature and relative humidity, but all tend toward values lower than formerly suggested for optimum storage.

2.1.1 Suggested Values for Temperature and Relative Humidity

For storage of records in libraries and archives the values in Table 1 are suggested.

Table 1: Suggested values for temperature and relative humidity

	Temperature (°F)	Relative Humidity (%)
Combined stack and user areas	70 (maximum)[a]	30-50 [b]
Stack areas where people are excluded except for access and retrieval	65 (maximum)[a]	30-50 [b]
Optimum preservation stacks	35-65 [c]	30-50 [b]
Maximum daily fluctuation	+/- 2	+/- 3
Maximum monthly drift	3	3

[a] These values assume that 70 °F is about the minimum comfort temperature for reading, and 65 °F the minimum for light physical activity. Each institution can make its own choice.

[b] A *specific value* of relative humidity within this range should be maintained +/- 3%, depending on the climatic conditions in the local geographic area, or facility limitations.

[c] A *specific temperature* within this range should be maintained +/- 2 °F. The specific temperature chosen depends on how much an organization is willing to invest in order to achieve a given life expectancy for its records.

2.2 Exposure to Light

These conclusions are drawn from a review of the literature:

1. Window glass filters ultraviolet light below about 330 nanometers (nm).
2. Through window glass, the part of the spectrum of a light source most damaging to cellulose is 330-400 nm.
3. Pure cellulose is transparent to light above about 330 nm in the ultraviolet to 450 nm in the visible. Therefore, absorption of light that degrades cellulose must be by chemical modifications of cellulose, impurities, lignin, other materials present in paper, etc.
4. Cellulose is degraded principally by photooxidation.
5. Photooxidation is enhanced by sulfur dioxide and nitrogen dioxide, and increases with increasing relative humidity.
6. Light filters are available that remove wavelengths of light below about 415 nm. This would eliminate most photochemical damage.

2.2.1 Suggested Guidelines for Exposure to Light

Light from windows, skylights, and fluorescent lamps should be filtered to eliminate wavelengths below 415 nm. However, if incandescent lamps are the sole source of light, the necessity for filters is questionable. To avoid damage to records while they are in use, reading stations should have lamps with appropriate filters to remove wavelengths below 415 nm.

In situations where budget constraints do not allow the ultimate in lighting control, the first choice is incandescent lamps, with as low wattage as consistent with reading comfort. The next choice would be fluorescent lamps with the smallest ultraviolet output available.

Sunlight through window glass and unfiltered skylight should be avoided because of their substantial ultraviolet component.

2.3 Gaseous Contaminants

The following provides some background on gaseous contaminants:

1. Sulfur dioxide, nitrogen dioxide and ozone are recognized as the principal gaseous contaminants of libraries and archives. In recent years many other contaminants, some indoor, have been recognized, such as acetic acid, formaldehyde and other aldehydes, mineral acids, hydrocarbons, and sulfides from protein-based glues, etc. From information in the literature, most or all of these may be removed by air purifiers, which usually are constructed with some form of activated carbon as the absorber (Kelly 1993).

2. The specification of maximum levels of gaseous contaminants depends on (a) the detection limits of instruments and (b) the capacity of filters to remove contaminants. Some instrumentation has been reported to detect sulfur dioxide and nitrogen dioxide down to 0.1 ppbv (parts per billion by volume), and ozone to one ppbv (Kelly 1993). Air purifiers are not likely to perform well enough to demand such sensitive instrumentation. From data in the literature, it would be more realistic to suggest maxima of about 10 ppbv for the three contaminants.

2.3.1 Suggested Maximum Levels

Suggested maximum levels of gaseous contaminants are:

	Parts/billion/volume
Sulfur dioxide	5 -10
Nitrogen dioxide	5 -10
Ozone	5 -10

2.4 Particulates

The following provides some background on particulates. Particulate matter covers a broad area of possible contaminants, generated both inside and outside a building. It is customary to remove most of the particulate matter by moving the air through filters, and the filter, depending on its porosity, will remove particles down to a specific size. Filters that remove smaller particles will have greater air resistance, and require more energy to move air through a system. It is impossible to remove all of the particulate matter by filtration.

2.4.1 Removal of Particulates by Air Filtration

The following are some suggested guidelines for removal of particulates by air filtration (ASHRAE 1976):

	Level of filtration (%)
Combined stack and user areas	60 - 80
Stack areas, users excluded except for retrieval	90 - 95
Optimum preservation areas	> 95

3. Monitoring of Control Devices

In order to maintain a controlled environment with respect to atmospheric contaminants, a monitoring program is necessary. The program can be handled by an engineer, scientist, conservator, or other appropriately trained individual, or by a consulting firm. A full-time program is the most desirable approach if funds are available, and if the air purification system removes impurities well enough that a first rate monitoring system is indicated. However, if funds are short, or if the air in the building is not filtered and cleaned, only occasional testing using less sophisticated monitoring devices is indicated. In any case, monitoring is an area that demands proper technical expertise.

The precision and accuracy of the monitoring system for air conditioning controls will dictate the necessary sophistication of the monitoring system. However, achieving precision and accuracy is not simple, because the situation must be approached as a total system that includes (a) the building, (b) the value of records, (c) geographic location, and (d) funds available, etc. Competent engineering talent is indicated.

4. Building and Facilities

The development of information on facilities is beyond the scope of this technical report. However, it is important to give proper attention to building structure, protection from water damage, fire safety, security, heat transfer limitations, vapor retardants, and lighting.

The success of a system for environmental control depends substantially on the characteristics of a building. This is especially true with respect to heat transfer (insulation), air infiltration, vapor retardants, and windows. Deficiencies in one or more of these areas can hamper or destroy the effectiveness of an environmental control system.

Competent engineering assistance is a requirement in order to avoid costly mistakes, or worse, complete failure.

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APPENDIX
Information Germane to the Development of Suggested Environmental Guidelines for the Storage of Paper Records

1 Introduction

Information used in the development of this technical report, derived from many sources and fields of study, is too extensive to include in the body of the report. The same is true of some material created especially for the report. Because this supporting information develops the rationale for the technical report it is provided here for those who wish to read more extensively.

2 Library and Archives Environments

2.1 Macroenvironment

The environment in a records repository is not uniform; it is a spectrum of environments. The macroenvironment, which may be defined as the general space in a building, contains a distribution of microenvironments. The temperature and relative humidity vary between limits, and these limits are different for each sub-element of an installation. The limits depend on infiltration, how well the building is insulated, the kind of heating system, whether the building is air-conditioned, the capacity of the air-conditioning system, the efficiency of the air handling system, accuracy of control devices, etc.

A macroenvironment has pockets of space that may not be as well regulated as the main space. Because of a distribution of values of temperature and relative humidity for each building, it is necessary to have enough general data on the performance of the HVAC (heating, ventilation, and air-conditioning) system to be able to set reasonable limits.

A well-constructed facility with an excellent HVAC system and competent technical oversight can be maintained at +/- 1 °F and +/- 2% relative humidity, but this is the most that can be expected of today's building construction and air-conditioning technology.

2.2 Microenvironment

Examples of microenvironments are the film of air on the surface of a record, a sheet of paper on a desk, a manuscript of 10 sheets of paper, a book, a shelf of books, an encapsulated document, documents in file folders in a filing cabinet, and documents or books in a document box. Each microenvironment in a records repository responds at a different rate to changes in temperature and relative humidity in the macroenvironment.

The number of situations in a library or archive can be infinite, depending on the size of the records unit which can range from one sheet of paper to a shelf packed with books. An isolated sheet will respond very quickly — within minutes — to changes in both temperature and relative humidity; a book may have only started to respond in the outside millimeter of thickness when the macroenviron-ment may have achieved a new set of conditions.

For books on shelves, and for records in document boxes with minimum openings, modest fluctuations in temperature and relative humidity of the macroenvironment from control limits will be significant only for the microenvironment at the surface of the record, including the edges of books. However, for books in use and for documents consisting of a few sheets, changes could occur rapidly in the book pages that are exposed, and in the document.

A book that is placed in a new environment with a different temperature probably will achieve temperature equilibrium in the interior of the book within a day. A change in relative humidity of the environment, assuming that the change is stable, will not effect a change in moisture content of the interior of the book for a long time, probably weeks or months (Nordman 1974). A report on the interaction of the climate in document boxes with a different macroclimate supports this conclusion (Preusser and Druzik 1989a, 1989b).

Passaglia has analyzed the microenvironment area and prepared a comprehensive research plan for it (1987).

3. Effect of Temperature and Relative Humidity on Records

3.1 Introduction

Temperature and relative humidity are important environmental elements that affect paper. Because temperature and relative humidity frequently are interdependent in their effects on paper, they are treated together.

The actual changes that occur during the degradation of paper consist mainly of oxidation, hydrolysis, changes in fiber bonding, changes in crystallinity or order, and crosslinking. It is not convenient, and in many cases not desirable, to measure these properties directly. The degradation process is measured indirectly through changes in physical properties such as folding endurance and tearing strength, in optical tests such as brightness, and in chemical tests such as pH and alkali solubility.

3.2 Effect of Temperature and Relative Humidity on Rate of Degradation

Arrhenius developed a mathematical relationship between reaction rate and the reciprocal of the absolute temperature (1889). He showed from this relationship, with rate data from several temperatures, a calculated activation energy, which is the minimum amount of energy necessary to cause molecular transformations or reactions.

From data on the physical and chemical testing of paper after accelerated aging at various temperatures, one can calculate an *apparent* value of activation energy. Values of apparent activation energy found in the literature for degradation of paper during accelerated aging range from below 20 kcal to about 35 kcal (Roberson 1976; Gray 1977; Du Plooy 1981). These values are indeed useful, but a value of activation energy obtained by measuring the secondary effects of degradation is an artifact of complex degradation processes and not necessarily that of a specific chemical mechanism. Erhardt and Mecklenburg (1995) provide values of activation energy for specific reactions.

After an apparent value for activation energy has been established, or selected from the literature, one can calculate relative degradation rates at various temperatures, using the Arrhenius equation, by selecting one temperature as a reference point, and assigning the reaction or degradation rate a value of *one* at this temperature.

The data in Table 2, which are plotted in Figure 1, were developed in this way, assuming an activation energy of 20 kcal, and a relative reaction rate of *one* at 70°F (21°C) and 50% relative humidity. Relative humidity does not enter into the calculations using the Arrhenius equation, but by extrapolation from the work of Graminski et al (1979), and Erhardt (1995), one can estimate the values of relative degradation rates at other relative humidity values.

Table 2: Comparison of relative degradation rates of paper at various temperatures

Based on the Arrhenius equation (Arrhenius 1889), with the rate at 21 °C (70 °F) and 50% relative humidity arbitrarily assigned a value of *one*. An activation energy of 20 kcal is assumed. Degradation rates at various relative humidity values are extrapolated from the work of Graminski, Parks, and Toth (1979). Also see Erhardt and Mecklenburg (1995) for more data on influence of RH on degradation rate.

Temperature		Relative Humidity (%)				
		25	30	40	50	75
°C	°F	Reaction rates relative to 21°C (70°F) and 50% RH				
60	140	28.00	33.00	44.00	55.00	83.00
55	131	17.00	21.00	28.00	35.00	52.00
50	122	11.00	13.00	17.00	22.00	33.00
45	113	6.60	8.00	11.00	13.00	20.00
40	104	4.00	4.80	6.40	8.00	12.00
35	95	2.40	2.90	3.80	4.80	7.10
30	86	1.40	1.70	2.20	2.80	4.20
25	77	0.80	0.90	1.30	1.60	2.40
21	70	0.50	0.60	0.80	1.00	1.50
20	68	0.45	0.53	0.71	0.89	1.30
18.3	65	0.37	0.44	0.58	0.73	1.10
15	59	0.25	0.29	0.39	0.49	0.74
10	50	0.13	0.16	0.21	0.26	0.39
5	41	0.07	0.08	0.11	0.14	0.21
0	32	_	_	-	0.07	_
-18	0	_	_	-	0.005	_

Note: In some cases the calculations of relative reaction rates are carried out to two, or even three, decimal places. This is only to obtain relative degradation rates within the system of calculations, and is not a reflection of the accuracy of the data.

Relative degradation rates are calculated using the logarithmic form of the Arrhenius equation:

$$\log \frac{k_2}{k_1} = \frac{E}{2.303\,R} \quad \frac{T_2 - T_1}{T_2 T_1}$$

T = absolute temperature, (°C + 273)
k_1 = reaction rate at reference temperature T_1 (273 + 21)
k_2 = reaction rate at other temperature, T_2
E = activation energy, kcal (20 kcal assumed for this application.
R = molar gas constant, 1.986 cal/deg/mole

Relative reaction rates, although not quantitative, can provide valuable information to the archivist and librarian concerning possible consequences of storing records under various conditions of temperature and relative humidity.

Table 2 and Figure 1A show that high temperatures, such as might occur in an attic or warehouse, are dramatically deleterious to records. Although no manager would willingly make use of such facilities, this choice might need to be made on a temporary basis.

A facility that is hot during the day and cool at night is especially harmful, as cycling of temperature and relative humidity accelerates degradation (Cardwell 1973; Shahani, Hengemihle, and Weberg 1989).

3.3 Low Temperature Storage of Paper-Based Records

Low temperature storage may be defined as (a) a fixed temperature in the range 35-65 °F, or (b) deep freeze temperature, about 0 °F. Some records facilities maintain their holdings below 68°F. Storage of paper-based records in a deep freeze in a records facility has never been reported, although color photos sometimes are stored at temperatures below 32 °F.

Of considerable relevance is the great gain in longevity (indicated in Table 2 and Figure 1B) that could be achieved with deep-freeze storage of records. This approach should be especially useful for records that are unusually valuable, in poor condition, and infrequently used. It has been noted by Kopperl and Bard (1989) that ice crystals do not form in photographs at 0°F if the photographs have first been equilibrated at 25-35% relative humidity before sealing in waterproof bags for storage in a deep freeze. Flyate and Grunin (1975) found that ice crystals do not form in cellulose at moisture contents resulting from equilibrium at about 55%, and lower relative humidity.

It appears, then, that paper may safely be stored at deep freeze temperature. However, as with photographs, before storage at temperatures below freezing, paper records should be equilibrated at about 30% relative humidity, and sealed in moisture-proof bags. Before sealing, as much air as possible should be squeezed from the bag. Upon removal, records should be allowed to reach temperature equilibrium with the room before opening the bag. The instructions given in ANSI / NAPM IT9.20-1995 (Imaging Materials—Reflection prints—Storage practice) for packaging photographs for low temperature storage could apply equally well to paper records.

3.4 Rheological Properties of Book Components

Rheological properties (creep, stress relaxation, load elongation, etc. as defined in the glossary) are important in the performance of paper (Mark 1983) and of other book components (Susich and Backer 1951) in bound volumes. Data on the physical properties of paper at relative humidities ranging from 20% to 90% have been developed (Crook and Bennett 1962).

Within the temperature range in which paper-based records may be used, temperature has little effect on physical properties. Relative humidity affects most physical properties, because the relative humidity determines the equilibrium moisture content of the paper. This, in turn, affects the performance and the properties of paper that can be measured in the laboratory.

A paper may elongate as much as 3% during use. Cotton fibers may elongate approximately 5%, and a thread composed of many fibers, depending on its construction, would elongate still more before breaking. Viscose, acetate, and nylon fibers exhibit elongations of 10-20% (Susich and Backer 1951).

Through creep and stress relaxation, a book or document may become distorted, as when a book is improperly shelved.

With time, the paper and paperboard in book covers, and the adhesives, tend to depolymerize, crystallize, and crosslink (Wilson and Parks 1979, 1980), and this greatly affects the rheological properties of book components. At this stage, the elongation will have been considerably reduced. The elongation of old papers may be increased 50-100% by wetting and drying (Wilson et al 1981).

Figure 1A: Degradation rates of paper at various temperatures and relative humidity values compared with an assumed rate of *one* at 21°C (70°F) at 50% relative humidity. Plot shows the extreme degradation that can occur at high temperature and/or high relative humidity, as in a non-airconditioned library, attic, or warehouse in summer.

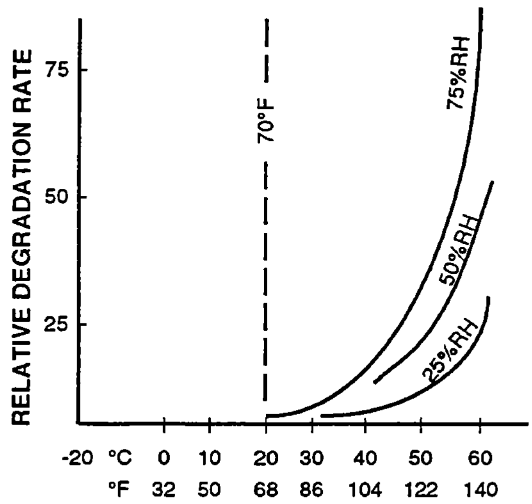
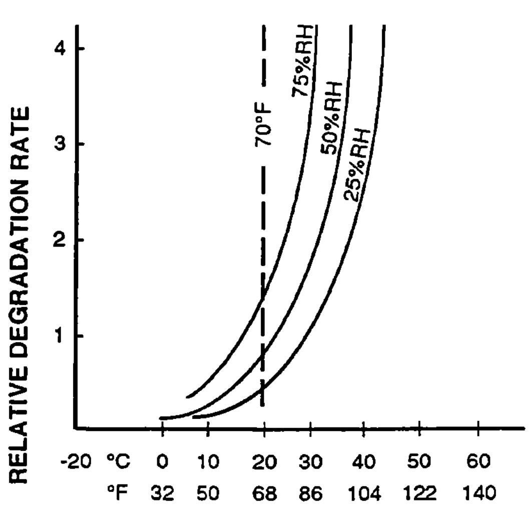


Fig. 1B: Degradation rates of paper at various temperatures and relative humidity values compared with an assumed rate of *one* at 21°C (70°F) at 50% relative humidity. The relative degradation rate scale is about one-twentieth that of Figure 1A. Plot shows the advantage of low temperature and/or low relative humidity storage on stability.



3.5 Temperature and Relative Humidity in Relation to Handling of Paper-Based Records

The suggested temperature values for records repositories historically have been for human comfort levels rather than for stability of records. A few repositories maintain temperatures below 68°F in stack areas; repositories in some parts of the world may have little or no heating in winter.

Historically, a relative humidity of 50%, or higher, has been recommended for the storage of records, because paper is more flexible at 50% relative humidity than at lower values of relative humidity. This practice has been based on the fact that the folding endurance of paper is two or three times greater at 50% relative humidity than at 25% (Crook and Bennett 1962). Although paper may be folded during use, especially in an archives, it normally is not folded under tension as it is in a folding endurance tester. Tests that more nearly simulate the wear and tear of use conditions are tearing strength and tensile energy absorption (see glossary). Because these tests are not nearly as sensitive to relative humidity as is folding endurance, it is questionable whether the emphasis on 50% relative humidity is justified, especially since paper-based records are twice as stable at 25% as at 50% relative humidity (Graminski, Parks, and Toth 1979). However, at extremely low values of relative humidity, leather and parchment may suffer an irreversible loss of moisture and flexibility if stored at a low relative humidity for an extended period. The critical value of relative humidity below which parchment loses flexibility is in doubt, but recent work shows that it is less than 25% (Shahani 1990; Hansen, Lee, and Sobel 1992).

Book covers usually consist of paperboard covered with cloth, heavy paper, leather, parchment, or some combination of materials. The adhesive for holding cloth or paper to the paperboard formerly was almost exclusively animal glue, but today it may be one of many synthetic adhesives. Because various parts of a book react differently to changes in relative humidity, and because the insides of covers respond more slowly to changes in relative humidity than covers do, warpage may occur with changing relative humidity. Parchment is especially sensitive to changes in dimensions due to changes in relative humidity. For a given relative humidity, collagen, the principal chemical entity in parchment and leather, contains about twice as much moisture as cellulose (Kanagy 1947).

3.6 Effect of Temperature and Relative Humidity on Mold Growth

Mold growth has been reported to occur from a little below freezing to somewhere above 55°C (131°F) at a relative humidity of 70%, or above (in Wilson and Wessel 1984). However, the 70% value is somewhat uncertain, as microenvironments may stray appreciably from the control value of the macroenvironment. To be safe, the control value for the macroenvironment probably should not exceed about 55%.

The fact that mold can be a threat to human health was discussed in *The Abbey Newsletter* in October 1994. The first paragraph and part of the second paragraph are reproduced here:

Mold as a Threat to Human Health

> Librarians and archivists who work with old books and papers are exposed to a wide variety of molds and other microorganisms, some of which are known to cause disease. Some of these diseases are chronic, some fatal. They can affect anyone, whether or not they have been previously sensitized to the organism.
>
> Yet few precautions are taken in this country, as a rule, to minimize exposure, and most cases very likely go undiagnosed, because initial symptoms often mimic the flu. Most people confuse such diseases with the allergic reactions produced by pollen and spores blowing in the air. So far there seem to have been no systematic studies of the prevalence and effect of fungal diseases among library and archival workers, though there has been a fair amount of research on mold in library materials—identifying the species, exploring ways to remove the stains, preventing the growth of the fungi, and so on.

Although how mold affects health is an area beyond the scope of this technical report, it is a question that deserves attention (Bales and Rose 1991).

4 Light

The energy of radiation increases as the wavelength decreases. Photolysis, the direct breaking of interatomic bonds in molecules, occurs in the ultraviolet light. The exact wavelength below which this occurs in cellulose is unknown, but it probably is below 340 nm (Padfield 1965).

As part of the *primary* process, sorbed radiant energy may be converted by a molecule to light, heat, or fluorescence, or it may be transferred to another molecule by collision. In the latter case, other reactions may now take place, and this is known as the *secondary* process. Reactions of interest to the archivist and librarian are mostly the secondary type, of which photooxidation is the most important.

The relative damage to cellulose by light, on an arbitrary scale with respect to wavelength, has been calculated as follows (NBS Circular 505, 1951; Judd 1953; NBS Circular 538, 1953; Harrison 1954):

Wavelength *nm*	Relative damage *arbitrary scale*
546	1
436	22
405	60
389	90
365	135

Thus, damage to paper by exposure to light could be reduced to a low level by the use of a filter that excludes wavelengths shorter than about 415 nm.

A photochemical reaction cannot take place unless radiation is absorbed. Cellulose is transparent in the wavelength range of interest to the records custodian — 330 to 460 nm — so radiation must be absorbed by functional groups formed during modification of cellulose during cooking and bleaching; by impurities; by sizing agents such as rosin, lignin, and resins; and by additives incorporated for special purposes, etc. Launer and Wilson (1943) found that light absorption increased dramatically from new rag to soda-sulfite to newsprint, and changes after irradiation followed the same pattern.

The degradation of cellulose by light in the 330–460 nm range is mostly a photooxidation process, i. e., oxygen must be present for a reaction to occur (Launer and Wilson 1943). It has been reported that the photodegradation of cellulose is accelerated by sulfur dioxide and nitrogen dioxide (Jones 1936; Little 1964) and by humidity (Launer and Wilson 1943). Thus, light, nitrogen dioxide, sulfur dioxide, and moisture are synergistic in promoting the degradation of cellulose.

In the absence of heat effects, paper that does not contain lignin is bleached when exposed to light, and then darkens when stored in the dark (Launer and Wilson 1943; Feller, Curran, and Bailie 1984). Even newsprint is bleached when irradiated in the absence of oxygen (Launer 1943). Launer called this the post-irradiation effect, and it subsequently has been attributed to free radicals that were fairly stable, and which degraded slowly with time (Kalnins 1966).

Light-sensitive dyes and some colorants are vulnerable to light in the wavelength range above 415 nm and even above 460 nm. Special care must be exercised to protect such documents from unnecessary exposure.

Books normally are on the shelf, and manuscripts usually are in files or document boxes, so exposure occurs only while the book or document is in use. However, the spines of books are vulnerable, and the great number of faded spines are mute evidence of damage.

Although special light sources are available for archives and libraries, the principal light sources are (a) fluorescent lamps, (b) incandescent lamps, and (c) skylight through window glass. Skylight through window glass has a very substantial ultraviolet component, more than direct sunlight alone, and should be avoided. The ultraviolet component of fluorescent lamps varies, but is far less than skylight. Incandescent lamps have a very small ultraviolet component (Harrison 1954).

Window glass transmits light in the wavelength range above 330 nm and light above 460 nm causes negligible damage to paper, so the archivist and librarian are interested only in that part of the spectrum from 330 to 460 nm. The ultraviolet portion from 330 to 400 nm is the most damaging. Fading of some media, such as organic colorants, may occur above 460 nm (Feller, Curran, and Bailie 1984; Padfield and Landi 1989).

Light filters vary in their characteristics and availability. A filter that removes most of the ultraviolet greatly reduces photochemical damage (Lee, Bogaard, and Feller 1989). A filter with a cut-off point of about 415 nm is desirable, because it cuts out the ultraviolet light, and does not absorb enough of the visible spectrum to change the color of the object being viewed. A filter with a cut-off point of about 460 nm would remove practically all radiation damaging to paper, but an object viewed in this light would appear yellowish.

The control of radiation exposure is desirable for objects especially sensitive to light. This may be accomplished by setting limits to the total radiation in lux-hours to which the object is exposed. Sensitive records should be segregated from the general records, or especially identified, so that special precautions may be taken for their protection.

Although many recommendations for the intensity of radiation for reading have appeared in the literature since 1920, they vary greatly. The minimum consistent with reading comfort is appropriate. The Illuminating Engineering Society Lighting Handbook (Applications Volume, 1987) provides some assistance in this area.

5 Air Contaminants

5.1 Kinds of Contaminants

Air contaminants consist of gases and particulate matter. Aerosols are classed as particulates.

The action of air contaminants on records is long term, and the effects usually do not show up for years. However, the damage can be devastating. Damage caused by sulfur dioxide occurs at one order of magnitude, but if the paper contains manganese, the latter will catalyze the oxidation of sulfur dioxide to sulfur trioxide, the anhydride of sulfuric acid. Damage by sulfuric acid, a very strong acid, is much greater than that caused by sulfur dioxide.

5.2 Gaseous Contaminants

The principal known gaseous contaminants are sulfur dioxide, nitrogen oxides, and ozone. Other contaminants, especially contaminants from indoor sources, may be detrimental to records over a long period of time, but their action has not been the subject of as much study.

5.3 Particulates

Most airborne particulates from outside, and also those generated within buildings, can cause abrasion and soiling of records. Particulates that are imbedded in paper may enhance sorption of gaseous contaminants. Of primary concern is elemental carbon from fossil fuel combustion.

Aerosols are suspensions of fine solid or liquid particles in gases. Although they seldom occur in a library or archive, they may be generated by certain types of humidifiers or by new concrete, and they may occur if air from smoking areas enters the stacks. Aerosols are filtered as particulates.

5.4 Sulfur Dioxide

Wilson and Wessell (1984) have summarized the action of sulfur dioxide on paper and the following conclusions may be drawn from data in the literature they considered:

1. Sulfur dioxide is readily sorbed by paper.
2. The amount sorbed depends on the kind of paper and the concentration of sulfur dioxide in the atmosphere.

3. Alkaline papers are especially good sorbers of sulfur dioxide, although appreciable damage would not be expected.
4. Certain metals that sometimes occur in paper act as catalysts in the oxidation of sulfur dioxide to sulfur trioxide, the anhydride of sulfuric acid.
5. The amount of sulfur dioxide sorbed increases with increasing relative humidity.
6. More degradation occurs at higher temperatures and higher relative humidity values.
7. Furnishings (drapes, furniture, clothing, etc.) readily sorb sulfur dioxide, so the indoor concentration in the inside air usually is substantially lower than in the air outside. Eventually, the furnishings would tend to become saturated.
8. Sulfur dioxide accelerates the photodegradation of cellulose.
9. Lower temperatures and lower relative humidity values tend to minimize the deleterious effects of sulfur dioxide.

5.5 Oxides of Nitrogen

The oxides of nitrogen are known to cause damage in cellulosic materials (Schreiber, Bullock, and Ward 1958; Gustaffson, King, and Forziati 1955; Wilson and Forshee 1959). In a study of the effect of sulfur dioxide on paper, Jarrell, Hankins, and Veitch (1938) used a gas flame that contained a small amount of sulfur compounds. Apparently the flame also generated oxides of nitrogen because the papers contained much more acid than could be accounted for from the sulfur content alone.

Nitrogen dioxide has been reported to accelerate the photodegradation of cellulose (Jones 1936; Little 1964).

5.6 Ozone

Ozone does not appreciably interact with unmodified cellulose, but cellulose that has been air-oxidized , hydrolyzed, and bombarded with air contaminants can hardly be termed unmodified, so ozone should be excluded from records areas. Ozone is especially damaging to some colors (Shaver, Cass, and Druzik 1983; Cass et al, 1991)

5.7 Other Contaminants

The presence of other contaminants from indoor surfaces may be difficult to measure, and their effects on records is difficult to determine. Some of these contaminants include, but are not limited to, formaldehyde and other aldehydes, acetic acid, mineral acids, aliphatic and aromatic hydrocarbons, sulfides from protein-based glues, and rubbers. The possibility of their presence, as well as the potential for long-term damage, must be recognized.

5.8 Removal of Gaseous Contaminants

Gaseous contaminants may be removed by granular absorption beds such as activated carbon, activated carbon impregnated with sodium hydroxide, activated alumina impregnated with potassium permanganate or wet scrubbers, or a combination of these. The beds have a high affinity for ozone, sulfur dioxide, and hydrocarbons. Although the technology for removing nitrogen oxides has been questionable, this problem appears to have been solved by improvements in technology (Kelly and Kinkead 1993; Parmar and Grossjean 1989).

Location of outdoor intakes should avoid local sources of high concentrations of contaminants, such as locations at street level, in loading dock areas, near exhaust discharges, or adjacent to unpaved parking lots. Some building codes permit the temporary suspension of outdoor air use, as during rush hour, in order to reduce entry of vehicle pollutants.

5.9 Removal of Particulates

Filtration to prevent soiling and particulate abrasion is of primary concern. As smaller particles, once deposited, are harder to remove from a surface, the higher the filtration efficiency below one micron the better, especially when filtering carbon particles.

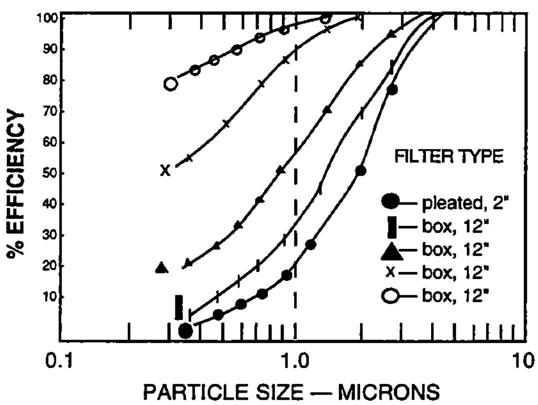
Thus, for maximum preservation of records, this technical report recommends High Efficiency Particulate Arrestant (HEPA) filtration in storage rooms where no outside air is introduced and no occupant activity occurs. HEPA filter efficiencies range from 95% to 99.9% using DOP methods (Dioctyl Phthalate Smoke Penetration Method, MIL-STD-282 [military standard]). HEPA filtering requires specially designed fan systems with powerful motors. They are cost prohibitive except in closed vault environments.

In other stack areas with occasional occupancy, a filtration level of 90 to 95% provides excellent small particle removal at a fraction of the cost of HEPA filtration. This level of filtration usually requires special fan system design. This design can rarely be retrofitted into an existing air handler using 30% or less filters. Table 3 and Figure 2 show the superior performance of 90 to 95% filtration over lower efficiencies.

Table 3: Dust spot ratings of various filters

Fan velocity (cu ft/min)	Filter type	Dust spot rating %	Initial pressure drop inches, water gauge
500	●—pleated, 2"	30	0.28
500	▌—box, 12"	45	0.25
500	▲—box, 12"	65	0.35
500	x—box, 12"	85	0.58
500	o—box ,12"	95	0.65

Fig. 2. Typical filter collection efficiency



In occupied rooms, the particulate volume generated by activity, clothing, and foot traffic makes the use of HEPA filtration impractical. While 90 to 95% filtration would be excellent, most facilities are currently equipped with commercial grade air handlers that provide 30 to 40% filtration. Upgrading such systems to at least the 60 to 80% level is recommended.

Inspection of the filtration plot above (Figure 2) shows that this upgrade provides a substantial improvement in submicron particle removal over lesser filters at only a nominal increase in air flow resistance. For this reason, existing air handlers probably can be retrofitted to house this improved filtration without major modification. Also, because a document's exposure time in these user areas should be relatively short, the lower filtration efficiency should not be detrimental.

6. Air Conditioning, Including Energy Considerations

6.1 General Considerations

Some broad guidelines on air conditioning are given here, but competent engineering assistance is necessary to ensure a properly operating system. In a new facility, the proper insulation, vapor retardant, lighting, cooling, heating, and air handling can be built in from the start, and temperature may be controlled to +/- 1°F, but a building with poor insulation and plenty of windows will vary much more than 1°F.

The development of a proper air conditioning system for cooling and for control of relative humidity is difficult enough in a well designed building, but in an old building it may be impossible without extensive renovation. It is desirable to control the relative humidity to +/- 2%. With modern technology and a well constructed building, this is possible in a temperate climate in the 40-55% relative humidity range. However, with less than perfect boundary conditions, about the most that technology can do for a reasonable price in a temperate climate is +/- 5%. Smaller areas for special purposes perhaps can be controlled to +/- 2%.

Achievement of relative humidity values in the 25-40% range in most temperate climates usually requires desiccant drying, and control to a set value is much more difficult. Control to a relative humidity lower than 40% in an arid climate would be more feasible. Ayers et al (1989) have prepared cost simulations for climate control in museums under various outdoor climates.

While close control of temperature and relative humidity is desirable, this is a matter of degree rather than kind. There are no definite limits of control of temperature and relative humidity within which records must be kept, and outside of which serious damage will occur. The ultimate constraints are cost and the capability of current air conditioning technology.

6.2 Some Practical Elements of Air Conditioning

6.2.1 Temperature and Relative Humidity

This technical report suggests temperature and relative humidity values on the basis of the needs of record materials, capabilities of HVAC systems, and the various climates where paper-based records can be found.

6.2.2 Northern Climates

Northern climates have hot, humid summers and cold, dry winters. Storage of paper-based records in these climates requires mechanical systems that produce heating, humidification, cooling and dehumidification.

Winter heating and humidification are usually produced by a ducted air heating system with water vapor injected into the air stream for humidification. During the winter season, the limiting factor in achieving the desired temperature and relative humidity usually is the thermal characteristics of the building itself. If interior moisture content is increased beyond the insulation capability of the windows and perimeter walls, condensation will occur, especially in unheated spaces. This will create an impossible control situation as well as building damage. A lower acceptable limit of 30% relative humidity can be used to great advantage in this situation.

Summer cooling and dehumidification requires both mechanical refrigeration equipment to subcool the air to condense moisture, and heating equipment downstream to reheat the air to a temperature suitable for the room.

The most common form of refrigeration equipment is the direct-expansion type that uses halogenated hydrocarbons as the cooling medium. When combined with reheat, the lower limit these systems can produce is about 65 °F and 45% relative humidity. At lower values of temperature and relative humidity the cooling coils ice over and special defrost cycles are needed such as are used in commercial food freezing operations.

In the other common method of refrigeration, chilled water is passed through cooling coils in an air stream to subcool the air. Down stream, the air may be heated by one of several methods. The lower limits of this system are about 70 °F and 50% relative humidity.

Generally, custom equipment is required to achieve temperatures below 65 °F. Brine or glycol solutions are used for this purpose in industrial environments. Concurrent maintenance of a specific relative humidity rarely is attempted.

The environments of buildings with thermal weaknesses may be allowed to drift (change slowly) to coincide with the changes of the seasons. This use of drift can be seen in Table 4 which shows a sample climate schedule, designed to follow the changes of the seasons, in an unoccupied storage room.

6.2.3 Arid Regions

In arid regions, it can be a hardship to achieve this technical report's relative humidity at the higher range of 30–50%. Large fluctuations from infiltration could result. Because 30% relative humidity is far better for stability of records than 50%, a relative humidity, as low as 30%, is recommended for arid regions.

6.2.4 Tropical Climates

Tropical climates are similar to northern summer conditions, but they continue year-round. Remarks under 6.2.2 on northern climates in summer apply here. Vapor retardants in a building's exterior walls are essential in a tropical climate.

Table 4: Use of drift to protect a building and its contents (Example)

Season	Month	Room temperature °F	Room relative humidity %
Winter	December	60	38
	January	57	35
	February	57	35
Spring	March	60	38
	April	63	41
	May	66	44
Summer	June	69	47
	July	72	50
	August	72	50
Fall	September	69	47
	October	66	44
	November	63	41

7. Building and Facilities

Although the development of information on building construction and facilities is beyond the scope of this technical report, it is appropriate to emphasize that a successful environmental program is dependent on a building's construction. These are the topics that must be considered (others may be added according to circumstances):

Architecture of the building
Basic construction of the building
Heating and air conditioning
Insulation
Vapor retardants
Windows
Lighting
Fire suppression system
Drainage
Vulnerability to flooding
Security

A properly constructed facility can save thousands of dollars in maintenance and energy costs.

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Glossary

Activation energy. Activation energy is a measure of the energy that must be supplied to a molecule before a reaction occurs. Because of experimental difficulties, molecular transformations that cause degradation in cellulose and paper are seldom observed directly. Secondary physical and chemical changes that can be measured in the laboratory are used to follow changes in cellulose and paper, and the value of activation energy calculated from these data is an empirical value (Gray 1977). For additional references see any physical chemistry text.

Air contaminants. Air contaminants are any unwanted gaseous, liquid, or particulate matter in the atmosphere. The principal outdoor contaminants include particulate matter, sulfur dioxide, oxides of nitrogen, and ozone. Some contaminants from indoor sources may include nitrogen oxides, mineral acids, aldehydes, sulfides from protein-based glues, rubbers, and acetic and formic acids.

Archives. Archives are (1) the non-current records of an organization or institution preserved because of their continuing value; in this sense, such records are also referred to as archival materials or archival holdings; (2) the agency responsible for selecting, preserving, and making available archival materials, also referred to as an archival agency; (3) the building or part of a building where such materials are located, also referred to as an archival repository. In American usage, the term *archives* is generally a plural or collective noun, although the form *archive* has been applied to a number of special collections (Evans, Harrison, and Thompson 1974).

Arrhenius equation, Arrhenius plots. Arrhenius discovered that an empirical relationship existed between reaction rate and temperature, and that this relationship allowed, when proper experimental data were available, the calculation of the activation energy of the reaction (1889). If data are available on rates of degradation of cellulose at several accelerated aging temperatures, relative stability at lower temperatures can be estimated. This approach, while useful, has a high degree of uncertainty (for reference see any physical chemistry text).

Book. For the purpose of this technical report, a book is considered to be a bound record.

Creep. See **Rheological properties.**

Deterioration. Loss of properties of a material so that the usefulness of the material is impaired or destroyed. The basic changes occur at the molecular level, and they are usually difficult to measure directly. Deterioration usually is measured indirectly with empirical tests that can be carried out in the laboratory.

Document. For the purpose of this technical report, a document is a book or an unbound record.

Document box. An opaque, rigid container for storage of records, used to prevent physical damage and damage from air contaminants. Usually made of cardboard.

Drift. A gradual change of value of temperature or relative humidity over a long period of time, usually following seasonal changes.

Fluctuation. Rapid changes of value (e. g., temperature or relative humidity), generally cyclic in nature. Typical causes are infiltration of air from adjacent space, cycling of HVAC equipment, and thermal heat load variations.

Infrared radiation. Electromagnetic radiation lying in the wave-length interval from about 800 nm to an indefinite upper boundary sometimes set at 10,000 nm.

Leather. A material made from animal skins by one of several procedures in which a tanning agent combines with the active sites in the protein (collagen) to form a material that is strong and durable, but not necessarily permanent. Used for centuries as a covering for bookbindings.

Library. A collection of books, pamphlets, and similar materials arranged to facilitate reference; a building or room housing such a collection.

Life expectancy (LE). The length of time that information is predicted to be retrievable in a system under extended storage conditions. Life expectancy designation (LED) is a rating in years for the life expectancy of records, e. g., LE-1000, indicates that the records are expected to be usable for 1000 years (ASTM Standards, 1995).

Light filter. A light filter is a material that absorbs a portion of the ultraviolet, visible, or infrared spectrum. It may be glass, plastic, or a chemical solution. The absorption curves of filters, where transmittance of light is plotted against wavelength of light, usually are S-shaped curves. The mid-point of the essentially straight-line portion of the curve is defined as the cut-off point of the filter. Thus, there is some absorption of light by the filter *above* the cut-off point, and some transmittance of light *below* the cut-off point. These are very small and can be ignored in most cases (Koller 1965). See any physical chemistry text for further information.

Load elongation. See **Rheological properties**.

Low temperature storage. Storage of records at temperatures below ambient, such as refrigerator temperature (35 - 40 °F), special installations (a temperature within the range 35 - 65 °F), or deep-freeze temperature (0 °F).

Macroenvironment. The large open space, or spaces, in a records repository.

Microenvironment. A small space within a macroenvironment; it may be the film of air on the surface of a record, the inside of a document box or file folder, the inside of a filing cabinet, interior of a book, etc.

Paper. Paper is the name for felted sheets of fiber (usually vegetable, but sometimes mineral, animal, or synthetic) formed on a screen from a water suspension that may include fillers, sizing, and other chemical agents.

Parchment and vellum. Materials made from the skins of sheep, goats, calves, and other animals by removing the hair and fat with lime, and then stretching, scraping, and rubbing with powdered chalk, pumice, gypsum, egg-white, etc. Vellum is a fine parchment usually made from the skins of calves, kids or lambs. There is no absolute distinction between parchment and vellum. Both have been used mainly as writing support material, but they also have been used to cover bookbindings. Tanning materials are not normally used in the manufacture of parchment.

Permanence. Capacity to retain properties such as strength and color over extended periods of time. It is influenced by internal factors (e. g., chemical composition) and external conditions (e. g., light, temperature, relative humidity, and atmospheric contaminants). The current trend is to substitute the term *life expectancy* for *permanence.*

Photometric terms. (Koller 1965; IES 1987; any physical chemistry text)

1. **Candle (candella).** The International System (SI) unit of luminous intensity. One candle is defined as the luminous intensity of one sixtieth of one sq cm of projected area of a black body radiator operating at the temperature of freezing platinum, 1772 °C.
2. **Lumen.** The unit of luminous flux. It is equal to the flux through a unit solid angle (stearadian) from a uniform point source of one candle, or to the flux on a unit surface, all points of which are at unit distance from a uniform source of one candle.
3. **Lux.** The SI unit of illumination in which the meter is the unit of length. One lux = 0.0929 footcandle.
4. **Footcandle.** The unit of illumination when a foot is the unit of length. One footcandle = 10.76 lux.

Preservation collections. Collections of records for which long-range preservation is important. In such collections, use of original documents may be restricted, and in special cases, use may be limited to the making of service copies, such as photocopy or microfilm.

Record box. See **Document box**.

Repository. For the purpose of this technical report, a repository is considered to be a library, archives, historical society, or museum in which documents of long-term value are housed.

Retention requirement. A policy decision concerning how far into the future a record is to be retained.

Relative humidity. The ratio of the quantity of water vapor in the atmosphere to the quantity of water vapor which would saturate the atmosphere at the existing temperature. Also, the ratio of the pressure of water vapor present in the atmosphere to the pressure of water vapor required to saturate the air at the existing temperature.

Rheological properties. Rheology is the study of the deformation and flow of matter. The mechanical behavior of materials (matter) is described in terms of rheological properties which are load (or stress), elongation (or strain), and time. These properties are measured in the laboratory by means of a load-elongation machine that continuously records tensile load and elongation as a test specimen is stressed to failure (Mark 1983). Related terms:

1. **Load.** The force on the specimen at any point of time as it is stressed to failure.
2. **Stress.** The load per unit cross-sectional area of the specimen.
3. **Tensile strength.** Load at break.
4. **Elongation.** The increase in length of the specimen at any value of load during the test.
5. **Strain.** Elongation expressed as a percentage of the length of the specimen.
6. **Tensile energy absorption (TEA).** Energy or work required to break a specimen of material when it is elongated in a load-elongation testing machine. Mathematically it is the area under the stress-strain curve. TEA is related to the capacity of a paper to withstand use.
7. **Creep.** Elongation vs. time of a material at a constant load
8. **Stress relaxation.** Decrease in stress that occurs over time when a material is held at constant elongation.

Skylight. Light that radiates from the sky because of scattering of sunlight by air. In contrast, outer space has no skylight for there is no atmosphere. The ultraviolet component of skylight is of the same order of magnitude as that of direct sunlight (Harrison 1954; Koller 1965).

Ultraviolet radiation. Roughly that part of the electromagnetic spectrum from 200 to 400 nanometers. The spectrum of sunlight and skylight reaching the earth extends down to about 260 nm. Because window glass filters out radiation shorter than about 330 nm, a keeper of records is interested in ultraviolet radiation only between 330 and 400 nm. (Koller 1965).

Vellum. See **Parchment and vellum.**

Visible light. The visible spectrum ranges from about 400 to 800 nm. Only that part of the visible spectrum from 400 to about 450 nm is considered damaging to paper, although some fugitive dyes are faded by longer wavelengths of visible light. (Koller 1965; Saunders and Kirby 1994).

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