T. Schneider (Editor)/*Acidification and its Policy Implications*

EFFECTS OF ACIDIFICATION ON ARTIFACTS IN ARCHIVES AND MUSEUMS

N.S. BAER

Conservation Center, New York University, 14 East 78th Street
New York, New York (U.S.A.)

ABSTRACT

The pollutant sources leading to indoor acid deposition; types of damage observed; and SO_2 and NO_x levels measured are reviewed for archives, libraries and museums. Recently proposed air quality design criteria for heating, ventilation and air conditioning (HVAC) systems for cultural institutions are presented.

INTRODUCTION

The effects of acid deposition on cultural property in archives, libraries and museums have previously been reviewed in the context of indoor air pollution (ref. 1,2), indoor particulate deposition (ref. 3), acid deposition effects on cultural property (ref. 4), and air pollution damage to materials (ref. 5,6). In the following discussion the sources of indoor acid deposition, typical manifestations of damage, pollutant levels observed, and suggested design criteria for air handling systems are considered.

HISTORICAL BACKGROUND

Soon after the introduction of coal as a fuel for kilns in England, complaints were made regarding smoke. In the records of Dunstable it was noted that in 1257 Eleanor, Queen of Henry III, left the town of Nottingham because of smoke from sea-coal. In the reigns of King Edward I and Queen Elizabeth proclamations forbidding the use of coal during the sitting of Parliament were issued (ref. 7).

Brimblecombe has demonstrated that such concerns received official attention as early as 1284 when a Royal Commission was appointed to investigate air pollution from coal used as a fuel for kilns in London and Southwark (ref. 8-11). In the seventeenth century many references were made to pollutant soiling of household materials. Evelyn in his Fumifugium or, The Inconvenience of the Aer, and Smoake of London Dissipated, published in 1661, wrote:

> It is this horrid Smoake which obscures our Churches, and makes our Palaces look old, which fouls our Clothes, and corrupts the Waters, so as the very Rain, and refreshing Dews which fall in the several Seasons, precipitate this impure vapour, which, with its black and tenacious quality, spots and contaminates whatever is exposed to it.
>
> It is this which scatters and strews about those black and smutty Atomes upon all things where it comes, insinuating itself into our very secret Cabinets, and most precious Repositories: Finally, it is this which diffuses and spreads a Yellownesse upon our choycest Pictures and Hangings... (ref. 12).

In 1850 a commission composed of Charles Eastlake, Michael Faraday and William Russell reported to the House of Commons:

> In considering the position of the National Gallery, our attention was drawn to the vicinity of several large chimneys, particularly that of the Baths and Washhouses, and that connected with the steam-engine by which the fountains in Trafalgar-square are worked, from which smoke are emitted. In the neighbourhood, also, the numerous chimnies of the various club-houses are constantly throwing out a greater body of smoke than those of the ordinary private residences...(ref. 13).

In addition to the dust and smoke that entered the building as windows were opened to provide ventilation, specific pollutants were associated with the visitors:

> ...the greater also will be the quantity of impurity produced within the building from the respiration and perspiration of great numbers of persons; this impure mass of animal and ammoniacal vapour, of which it is difficult and perhaps unnecessary to distinguish and define the component parts, is peculiarly liable to be condensed on the surface of the pictures... (ref. 13).

The results of the assault of various forms of pollutant deposition on the pictures were immediately obvious:

> Many of them present the appearance of being covered with a thick film, alike foreign in feature and in color to the original character of the picture, detracting from its highest qualities, and depriving it for the time of clearness and brilliancy (ref. 13).

More recently, Hudson studied the acidity of paper in books from two libraries; Chatsworth, in open country, some 25 miles east of Manchester; and the Portico Library located in the polluted urban atmosphere of Manchester (ref. 14). Surface pH measurements were made at the top, center and side of pages for 25 identical copies of books. Hudson concluded that atmospheric pollution was a cause of the lower pH values observed, particularly at the edges of the books in the Portico Library. A statistical evaluation of these data concluded that to the degree that contact pH for the two groups of books can be attributed to library location and position on the page, the low pH at the edges as compared to the less exposed center may be attributed with great confidence to the differing conditions of storage at the two libraries (ref. 15). However, this and other retrospective studies have encountered difficultly in separating the effects of local SO_2 concentrations from variations in average annual temperature, frequency of use, and differing maintenance practices.

POLLUTANTS AND THEIR EFFECTS

Indoor pollutants in archives, historic houses, libraries, and museums derive from outgassing of structural or decorative materials, heating plants, activities of visitors and staff, and the intrusion of outdoor pollutants. In some cases the artifacts themselves emit significant and possibly dangerous amounts of pollutant gases. The types of damage observed, principle air pollutants causing damage, other significant environmental factors, and methods of measuring damage are given in Table 1.

TABLE 1.
Indoor Air Pollution Damage to Materials.

Material	Type of Impact	Principal Air Pollutants	Other Environmental Factors	Methods of Measurement
Magnetic Storage Media	Loss of signal, tape failure	Particles, moisture	Abrasion wear	Signal quality, physical and chemical analysis
Metals	Corrosion, tarnishing	Sulfur oxides, and other acidic gases, hydrogen sulfide	Moisture, air, salt, particulate matter, ozone	Weight loss after removal of corrosion products, change in surface characteristics
Paintings and Organic Coatings	Discoloration, soiling	Sulfur oxides, hydrogen sulfide, alkaline aerosol	Moisture, sunlight, ozone, particulate matter, microorganisms	Surface reflectivity loss, chemical analysis
Paper	Embrittlement, discoloration, acidification	Sulfur oxides	Moisture, physical wear, acidic materials introduced in manufacture	Decreased folding endurance, pH change, molecular weight measurement, tensile strength.
Photographic Materials	Microblemishes, "sulfiding"	Sulfur oxides, hydrogen sulfide	Particulate matter, moisture	Visual and microscopic examination
Textiles	Reduced tensile strength, soiling	Sulfur and nitrogen oxides	Particulate matter, moisture, light, physical wear, washing	Reduced tensile strength, chemical analysis (e.g., molecular weight), surface reflectivity
Textile Dyes	Fading, color change	Ozone, nitrogen oxides	Light, high temperature	Reflectance and color value measurements
Leather	Weakening, powdered surface	Sulfur oxides	Physical wear, residual acids introduced in manufacture	Loss in tensile strength, chemical analysis, shrinkage

Adapted from (refs. 1,3,5,6).

Acidic Gases

Of the pollutants affecting cultural property, SO_2 has received, by far, the greatest attention. As noted above, there is a long history of association of damage with SO_2 deposition. The high ambient SO_2 levels accompanying industrialization were seen to have increased the rate at which damage occurred, though other factors in some cases, e.g. the use of groundwood pulp and changes in papermaking practice were the root causes for the decline in permanence.

In recent years, increasing concern over NO_x has developed as ambient levels increased. With the possible exception of photographic microblemishes and damage to some textile fibers, few documented examples of damage to cultural property exposed to high ambient NO_x levels have been reported. More frequently, damage has been observed for objects exposed to organic acids given off by such construction materials as plywood, fiberboard and poly(vinyl acetate) adhesives. Particularly suseptible are lead objects where growth of lead acetate and lead formate transformation products seriously disfigure objects (ref. 1).

In general, atmospheric acidic gases are introduced into the museum or library environment as makeup air is brought into the HVAC system. Typically, 10% of the air in a cycle is taken from the exterior while 90% is recirculated. With an average of 6 air changes per hour, the museum environment, in the absence of pollutant removal, will soon equilibrate with exterior pollutant levels. That lower SO_2 and ozone levels are observed in museum and library interiors is a result of the high rate of deposition of these gases on paper, leather, textiles and other surfaces found in cultural institutions.

In Table 2 the measured indoor SO_2 and NO_x levels reported for libraries, archives, and museums are given. It is obvious that several technologies, e.g. water washing, activated carbon, potassium permanganate coated alumina (Purafil), are capable of effectively removing SO_2. Unfortunately, the wash

TABLE 2.
Measured Indoor-Outdoor Pollution Levels for Archives, Libraries and Museums.

Institution	Pollutant	Dates Measured	Exterior Concentration	Interior Concentration	Filtration System	Reference
NARS (Archives Building)	SO_2	Nov. 1977	32-40 ppb (10x reduction)	<3 ppb	Particulate	(16)
NARS (Archives Building)	SO_2	Dec. 1982-Jan. 1983	7-34 ppb[a] daily average	2-25 ppb	Particulate	(16)
National Gallery (East Building)	SO_2	Feb. 1983	7-34 ppb[a] daily average	$\leq$1 ppb	Water Wash	(16)
Library of Congress (Madison Building)	SO_2	Jan. 1983	7-34 ppb[a] daily average	$\leq$0.5 ppb	Purafil	(16)
Rijksmuseum (Amsterdam)	SO_2	Feb.-Mar. 1976	9-57ppb	1-6 ppb	—	(4)
Tate Gallery (London)	SO_2	1980-1983	12-80 ppb	0-4 ppb	Activated Carbon	(17)
Victoria & Albert (London)	SO_2	Jan.-Feb. 1983	22-60 ppb	3-42 ppb	None	(17)
NARS (Archives Building)	NO_x	Sept. 1977	41 ppb average	20-80 ppb[b]	Particulate	(16)
NARS (Archives Building)	NO_x	Dec. 1982-Jan. 1983	10-527 ppb[a]	10-252 ppb	Particulate	(16)
National Gallery (East Building)	NO_x	Feb. 1983	40-92 ppb[a]	7-50 ppb	Water Wash	(16)
Library of Congress (Madison Building)	NO_x	Jan. 1983-Feb. 1983	46-318 ppb[a]	4-154 ppb	Purafil	(16)
Huntington Library (San Marino, CA)	NO	Oct.-Nov. 1984	36ppb	37ppb	Particulate	(2)
	NO_2		44ppb	38ppb		

[a] Measured at 24th and L Streets, N.W., by the District of Columbia.
[b] Followed exterior.

and Purafil systems are much less effective for NO_x removal than for SO_2 removal. These results are surprising since Purafil is clearly effective in the laboratory.

AIR QUALITY STANDARDS FOR ARCHIVES, LIBRARIES AND MUSEUMS

There is compelling evidence that improved air quality reduces the rate at which damage occurs to cultural artifacts. This has led to the widespread introduction of temperature and humidity control systems, the increased use of particulate filtration, and in recent years the introduction of pollutant gas removal in HVAC systems. In drier areas with high ambient ozone levels activated carbon systems have been introduced, while in more humid areas with higher SO_2 and NO_x levels these pollutants are removed by water wash or impregnated alumina systems. At present, relatively few HVAC systems in museums have been designed for high removal efficiency for the primary pollutants: particulates, ozone, sulfur dioxide and nitrogen oxides. It does not appear that any are truly effective in removing NO_x and fine particulates i.e. $<2\mu$ diameter; while most of the newer systems adequately remove ozone and SO_x. Differing local pollution concentrations and environmental concerns coupled with differing philosophies of pollutant regulation have led to a range of proposed criteria. These have been tabulated by Baer and Banks (ref. 1,3).

In a report recently prepared by the Committee on the Preservation of Historical Records, National Academy of Sciences, for the U.S. National Archives and Records Administration (ref. 2) a series of criteria intended specifically for the National Archives Building was prepared (Tables 3 and 4). It is important to note that these criteria were intended for paper-based records and so would have to be modified for special collections, e.g. archaeological bronzes, photographic materials, lead artifacts, etc. Further, the inability of current systems to remove NO_x adequately led to a vague specifications of "best available technology" for this pollutant. There is, in this report, a significant emphasis on the removal of particulate matter. This is due to the

TABLE 3.
Recommended Standards for Paper-based Records in a Mixed Collection of Bound and Unbound Materials (standards to be met at the surface of the records).[a,b]

Environment	Control level
Temperature	68-72°F
Relative Humidity	40-50%
SO_2	$\leq$ 1µg m^3 (0.4 ppb)
NO_2, HNO_3	best available technology
O_3	$\leq$ 2µg m^3 (1.0 ppb)

[a] Specifications are averages over a 24 hour period. Small, short-term excursions outside these limits are permitted.

[b] After ref. 2.

TABLE 4.
Draft ANSI Particulate Standards for Paper-based Documents in Libraries and Archives [a]

System Filter Location	ASHRAE Weight Arrestance Efficiency	ASHRAE Atmospheric Dust Spot Efficiency	MIL-STD 282 DOP Efficiency
Prefilter[b]	≥80%	≥30%	≥ 5%
Intermediate Filter[c]	≥95%	≥80%	≥50%
Fine Filter[c]	N.A.[d]	≥90%	≥75%

(a) After refs. 3 and 18.

(b) For outside or makeup air.

(c) For supply (both outside and recirculated) air.

(d) N.A. denotes not applicable.

observation of Cass (ref. 2) that currently used filter systems are totally ineffective in removing the fine particulates that make up some 50% of the total mass load indoors.

An important design strategy suggested is an emphasis on the environment experienced by the individual artifact so that increased attention to the design of display cases, book boxes and encapsulation methods is a priority for research and development.

ACKNOWLEDGEMENT

This work was supported in part by a grant from the National Endowment for the Arts.

REFERENCES

1 N.S. Baer and P.N. Banks, International J. Museum Mangement Curatorship, 4, 1985, 9-20.

2 National Materials Advisory Board, Preservation of Historical Records, National Academy Press, 1986, Washington, D.C. chapter 3.

3 N.S. Baer and P.N. Banks, Pap. Proc. Ann. Meet-Air Pollut. Control Assoc., 1985, 78, 85-8.8.

4 J.F. Feenstra, Cultural Property and Air Pollution Damage to Monuments, Art-objects, Archives and Buildings Due to Air Pollution, Ministry of Housing, Physical Planning and Environment, The Netherlands, 1984, 142pp. English Translation.

5 J.E. Yocom and N.S. Baer, in The Acidic Deposition Phenomenon and its Effects: Critical Assessment Review Papers, U.S. EPA, Washington, D.C. EPA-600/8-83-016BF, 1984, chapter E-7, section 7.1.

6 J.E. Yocom, N.S. Baer and E. Robinson, in A.C. Stern (Ed.), Air Pollution, Volume VI, Academic Press, New York, 1986, chapter 4.

7 R.W. Frey, The Library Journal, 57, 1932, 405-414.

8 P. Brimblecombe, JAPCA 26, 1976, 941-945.

9 P. Brimblecombe, Atmospheric Environment, 11, 1977, 1157-1162.

10 P. Brimblecombe, JAPCA, 28, 1978, 115-118.

11 P. Brimblecombe, Notes and Records of the Royal Society of London, 32, 1978, 123-129.

12 J. Evelyn, Fumifugium, 1661. Facsimilie of the 1772 edition, Oxford, England, 1930.

13 C.L. Eastlake, M. Faraday, and W.S. Russell, "Report of the Commission Appointed to Inquire into the State of the Pictures in the National Gallery", House of Commons, May 24, 1850.

14 F.L. Hudson, Paper Technology, 8, 1967, 189-190.

15 N.S. Baer and S.M. Berman, Restaurator. In Press.

16 E.E. Hughes and R. Meyers, Measurement of the Concentration of Sulfur Dioxide, Nitrogen Oxides and Ozone in the National Archives Building, NSBIR 83-2767, National Bureau of Standards, Washington, D.C. 1983.

17 S. Hackney, Studies in Conservation, 29, 1984, 105-116.

18 American National Standards Institute, American National Standard Practice for Storage of Paper-Based Library and Archival Documents, Draft Standard, 1985.