AIR POLLUTION IN ARCHIVES AND MUSEUMS: ITS PATHWAYS AND CONTROL

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Indoor air studies focus almost completely on health issues and few have explored the damage to objects of cultural heritage indoors. The purpose of this study is to describe the fate of pollutants inside storerooms of archives and museums. A significant fraction of outdoor pollution is introduced by the ventilation system. It is only the rapid absorption on the large amounts of archival material which explains the apparently low concentration levels observed inside storerooms. A control strategy relying on increased recirculation ventilation assisted by the proper use of dispensable passive absorption surfaces is proposed.

INTRODUCTION

Concern exists about the condition of stored paper records and valuable books in many archives and libraries. Increasing quantities (up to 30%) are in such a deteriorating condition that immediate action like mass deacidification or transfer of information to more permanent recording media is warranted. In long term preservation of many cultural objects even pollutants at concentrations far below the levels of concern with respect to public health can be considered as causing damage. Although the rates of deterioration are slow, accumulated damage over years may reach unacceptable levels.
It is the exposure to SO_2, NO_2 and O_3 which causes hydrolytic and oxydative attack of paper.
In the Netherlands a large research plan was drawn up to provide a scientific basis for setting guidelines and recommendations for the preservation of paper records.
This paper discusses the results of the first two phases of research which include:

- Evaluation of the factors governing indoor air quality in archives and museums.
- Assessment of the uptake rate of SO_2, NO_2 and O_3 for various types of paper.

Recommendations derived from these studies are presented too.

METHODS

Concentration measurements in archives and museums

Indoor/outdoor concentration ratio's were measured in six buildings, three archives and three museums, located in cities, geographically representative for the various pollution levels in the Netherlands. Pollutants (SO_2, NO_2 and O_3) were simultaneously monitored in the fresh air intake of the ventilation system and inside a selected storeroom or exposition gallery.
In each building the monitoring period covered two weeks, one week in summer and one week in winter (except for O_3), in order to cover two climatologically different situations.

One of the archives (the Hague) was selected for in-depth studies of the concentration levels as a function of the balance between fresh and recirculated air. This archive is equipped with a modern, well maintained heating, ventilation and air conditioning (HVAC) system featuring a fine dust filter (ASHRAE dust spot 70-90%) in the fresh air intake, a steam humidifier in the supply duct and dampers to proportion the amounts of fresh and recirculated air. The storeroom monitored was one of eight stacked storerooms all supplied by a single HVAC unit located at the top floor. Air is supplied to the storeroom by two ducts each with a high number of supply diffusers and is exhausted via a single exhaust opening.
Apart from the two monitoring stations (one in the fresh air intake and one in the middle of the room) a third station was used to monitor concentrations in the supply diffusers. By controlling the dampers, fresh and recirculated air were proportioned over the range of 20 to 90% recirculation without much affecting the air exchange rate in the storeroom (0.5-0.7 h^{-1}).
Continuous injection of N_2O and infraredspectroscopy were used to determine infiltration rates and the balance between fresh and recirculated air.

Uptake of air pollutants by paper

Laboratory experiments were carried out using a 80 litre flow-through chamber consisting of a glass hemisphere sealed to a flat glass bottom plate. Preconditioned samples are introduced and removed through a removable section in the bottom plate. All samples tested were placed flat on the bottom plate. The exposed area of the paper samples was 620 cm^2.
A small mixing fan located in the top of the chamber induced an air velocity of 1.4 $m.s^{-1}$ at sample surface.
The chamber was continuously flushed with a gas mixtures of known composition at flow-rates of 108 to 288 $dm^3.h^{-1}$. Air temperature and humidity were kept at 20°C and 55% RH. Gas mixtures were prepared using permeation tubes (SO_2 and NO_2) or a mercury vapour lamp (O_3) in combination with a dynamic dilution system. Concentration generated were 60 $\mu g.m^{-3}$ SO_2, 65 $\mu g.m^{-3}$ NO_2 and 25 $\mu g.m^{-3}$ O_3.
The uptake of pollutant by the sample was determined by monitoring over a period of 70 hours, the concentration differences between de gas mixture entering (C_i) and leaving (C_e) the chamber. Steady state deposition on the walls of the chamber was corrected for. Deposition velocities were calculated from pollutant fluxes and the pollutant concentration in the air leaving the chamber.

Monitoring equipment
Field and laboratory measurements were all made by direct reading instruments, chemiluminescence monitors for NO_2 and O_3 and UV fluorescence for SO_2. The analog signals of the monitors were sampled every 150 seconds by a data acquisition unit. Weekly calibrations were carried out using a dynamic dilution/gas phase titration system with certified permeation tubes, an O_3 source and a $NO_2 \rightarrow NO$ converter.

RESULTS AND DISCUSSION

The results of the measurements of SO_2, NO_2 and O_3 in six buildings are presented in Table 1.

Table 1 One-week average concentration levels ($\mu g.m^{-3}$) in archives and museums. Between brackets indoor/outdoor ratio's (I/0).

Location	Summer			Winter	
	SO_2	NO_2	O_3	SO_2	NO_2
The Hague (archive, storeroom)	<2.5 (<0.2)	7 (0.35)	<1 (<0.03)	3.5 (0.08)	14 (0.10)
Arnhem (archive, storeroom)[a]	2.5 ( )[c]	7 (0.22)	4 (0.6)	12 (0.65)	25 (0.32)
Leeuwarden (archive, storeroom)	<2.5 ( )[c]	<2 (<0.1)	<2 (<0.03)	<2.5 (<0.04)	<4 (<0.1)
Amsterdam (museum, exposition gallery)	<2.5 (<0.1)	24 (0.59)	<2 (<0.06)	3.5 (0.20)	52 (0.73)
Rotterdam (museum, prints storage)	<2.5 (<0.1)	11 (0.37)	<2 (<0.1)	<2.5 (<0.1)	16 (0.24)
Middelburg (museum, tapestry display)[b]	<2.5 (<0.2)	4.5 (0.32	<2 (<0.04)	6 (0.12)	25 (0.39)

a: no humidifcation system; b: natural ventilation; c: outdoor concentration to low

A wide range of values is represented and averaged over a week most are extremely low.
The observation that indoor and outdoor concentrations closely track, indicates that outdoor concentrations are primarily responsible for changes in indoor levels.
For NO_2 the indoor/outdoor concentration ratio (I/0) is highest (0.1 to 0.7) and roughly a factor 3 higher than for SO_2 in buildings with HVAC's. Concentrations of O_3 are extremely low. The I/0's appear to be independent of the outdoor concentrations observed during the measurements. The low indoor concentrations measured seem rather reassuring, however strong indications were found that deposition processes in the storerooms and galleries play a dominant role in lowering the concentration levels. Owing to the sheer amount and surface area of paper records in storerooms, pollutants are readily observed thereby creating large concentration gradients in the rooms.

This was clearly demonstrated during the in-depth study in the Hague. Although a considerable fraction of outdoor pollutants is transmitted by the HVAC system and subsequently supplied to the storeroom, concentrations in the room drop very steeply to non-detectable levels, within the first 4 meters from supply diffuser. This results in almost clean air leaving the room which will dilute concentrations in the fresh air supply proportional to the recirculation rate.
A balance of the pollutant losses in the HVAC system is shown in Figure 1.

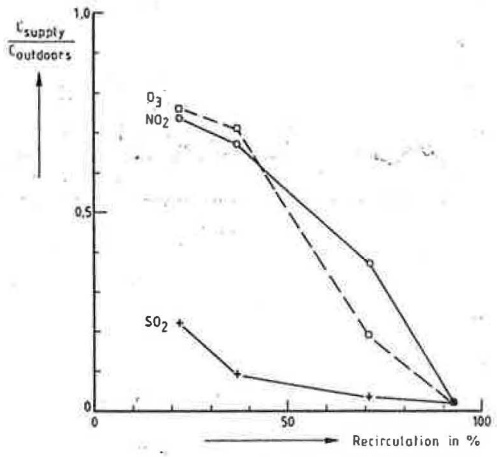

Fig. 1 Ratio between concentrations in the supply air to a storeroom and the concentration outdoors as function of the recirculation rate.

To a large amount SO_2 is absorbed in the HVAC system particularly in the humidification/dehumidification section.
NO_2 and O_3 pass the HVAC system almost unaffected and are only diluted by the clean recirculated air. A recirculation level of 90% in storerooms can be maintained since occupancy is only incidental. Figure 1 shows that in this case pollutant concentrations in the supply air of storerooms can be reduced to levels less than 10% of the concentration in the outdoor air.

Several official bodies have proposed air quality quidelines for archives and museums (1). In the absence of quantitative data on exposure/effect relationships these values center around natural background concentration levels (2-5 $\mu g.m^{-3}$ SO_2, 5 $\mu g.m^{-3}$ NO_2 and 2 $\mu g.m^{-3}$ O_3). At the current levels of pollution in Dutch cities this means that at 90% recirculation, concentrations of SO_2 and O_3 in the supply air will be around the guideline values (considered as annual means) whereas NO_2 will still exceed the guideline value. A significant further reduction of long term exposure can be achieved by changing over to 100% recirculation outside the working hours (Figure 2).

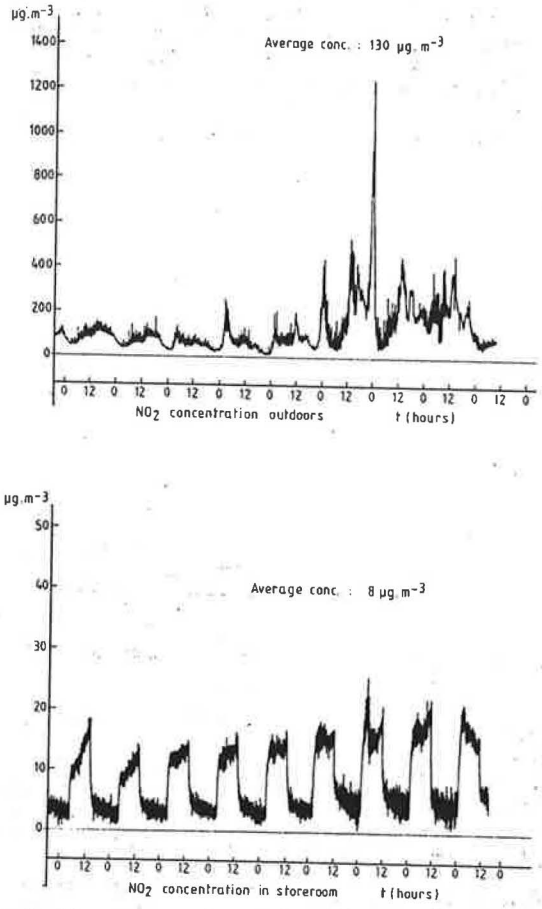

Fig. 2 The effect of night ventilation on the NO_2 concentration inside a storeroom.

Deposition velocities (V_d's) are presented in Figure 3.

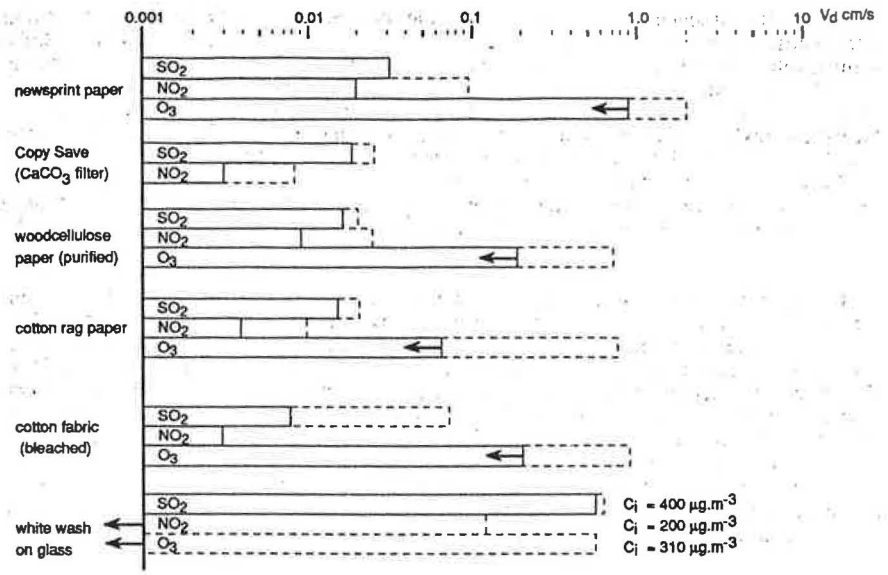

Fig. 3 Deposition velocities for various cellulose materials at ambient concentrations (C_i = 60 $\mu g.m^{-3}$ SO_2; 25 $\mu g.m^{-3}$ O_3; 65 $\mu g.m^{-3}$ NO_2) after 70 hours. Dashed lines represent initial (0-hours) deposition velocities. An arrow indicates that steady state conditions have not been reached after 70 hours.

On cellulose-containing materials the V_d for SO_2 centers around a value of 0.02 $cm.s^{-1}$ and appears to be constant over time (0-70 h) except for cotton fabric. Compared to SO_2 the V_d's for NO_2 are roughly a factor 2-5 lower. Initial V_d's for NO_2 are high but decline in the first 10 to 20 hours to a steady state value. The V_d for O_3 is the highest of all gases tested. After 70 hours the uptake rate is still declining. Compared to SO_2 the V_d's for O_3 are roughly one order of magnitude higher.

Between the paper samples tested, the V_d for SO_2 is not much affected by the type of paper. Even the alkaline paper (Copy Save) does not show a higher uptake rate suggesting that absorption is more likely to be controlled by diffusion resistance of the paper than by chemical reaction.
For NO_2 and O_3 the differences are more pronounced. News print paper showing the highest uptake for these gases, presumably due to the reaction with lignin, whereas cotton derived materials show the lowest uptake rates.
Additional experiments were carried out at concentration levels roughly a factor 5 to 10 higher. For SO_2 and O_3 V_d's decrease with increasing concentration, whereas the V_d for NO_2 is independent of concentration level (65-250 $\mu g.m^{-3}$). The V_d for SO_2 is by approximation proportional to the square root of the SO_2 concentration (60-450 $\mu g.m^{-3}$) confirming observations made by Edwards and Hudson (2).

The V_d for SO_2 on white wash is more than one order of magnitude higher than for cellulose materials. Although there is some initial absorption of NO_2 and O_3 the uptake decreases very rapidly to remain virtually zero after the first 10 hours. This means that white washed ceilings and walls have a potential as passive scrubbers for SO_2 but not for NO_2 and O_3.

CONCLUSIONS AND RECOMMENDATIONS

Outdoor pollutant levels are primarily responsible for exposure levels of archival material in storerooms. These exposure levels are dependent on how ventilation air is conditioned, the volume ratio between fresh and recirculated air, and the loading factor of the storeroom. HVAC systems equipped with humidifiers reduce SO_2 levels to a wide extend although probably at the cost of metal corrosion. NO_2 and O_3 pass the HVAC system almost unaffected. Measurements in storerooms and experimentally determined deposition velocities indicate that O_3, SO_2 and to a lesser extend NO_2 are very effectively absorbed by paper-based materials. Newsprint paper being most affected. Decisions on the acceptability of exposures depend very much on where the measurements are taken. It is recommended to control compliance with air quality guidelines by monitoring concentrations directly in the supply air to the rooms.

This study indicates that the storage environment of paper can be improved by relatively simple means. Exposure can be reduced significantly by increasing recirculation rates. Reductions achievable are proportional to the balance between fresh and recirculated air. Changeover to 100% recirculation outside the working hours will add to a further reduction of 75%. However, any reduction of fresh air supply should be approached with caution when indoor sources of pollutants are present. Another means of reducing SO_2 exposures is simply white washing walls and ceilings or placing white washed screens between the shelves. For NO_2 and O_3 such passive absorption devices are not effective.
Still little is known about critical loads below which paper degradation is acceptable. In view of the exposure levels and uptake rates found in this study special attention is drawn to the long-term effects of O_3 and NO_2 and combinations of these pollutants with SO_2.

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KEYWORDS

Indoor air quality SO_2, NO_2, O_3, museums, archives, effects on paper, deposition, ventilation strategies.