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FULL PAPER

EXPERIMENTAL AND COMPUTER SIMULATION APPROACH TO INVESTIGATING THE ENVIRONMENTAL PERFORMANCE OF A RARE BOOKS ARCHIVE

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This paper presents the findings of a case study of a rare books archive that seeks to balance the environmental needs of both the collection and users of the library. With the aid of physical data collection and computer simulations using computational fluid dynamics, the indoor environmental performance of the archive was analyzed. Data was collected on the archive's air temperature, humidity, light level, volatile organic compounds, particulates, mold, and formaldehyde. In addition, the mechanical system was investigated as was the design and construction of the archive and its maintenance and operation. Specific areas of investigation were ventilation effectiveness, temperature distribution, pollutant concentration, and possible indoor and outdoor sources of pollutants specific to the environment under investigation. Focus was placed on improving the overall local mean age of air and minimizing potential sources of pollutants as a result of maintenance and design. This study provides some insight into how architects, preservationists, conservators, and environmental engineers can collaborate to design more environmentally sound archive spaces.

1 Introduction

The design, construction, and operation of archive environments are unlike conventional buildings because they require the most stringent of indoor environmental conditions for the preservation of their collections. Although these buildings may have been designed with the best intentions, the actual conditions of the indoor environmental performance may be compromised over time. And without the appropriate team of specialist with knowledge of conservation environments and needs involved in the design and maintenance of the building, the indoor environmental performance may be further compromised.

This paper presents the findings of a pilot case study on the environmental performance of a rare books library situated on the campus of a major research university in the Midwest region of the United States

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of America. The building was built in 1968 and contains over 750,000 rare books and manuscripts dating from antiquity to the present day. The project was initiated by the library's staff because of their growing concerns over the building's ability to properly provide conservation level environmental control. Environmental monitoring of the archive by the staff was limited to air temperature and relative humidity levels using data loggers which only provided a narrow view of the indoor performance. In addition to those two variables, the staff was aware of condensation occurring in the gallery space (location D on Figure 1) during the fall and winter and accelerated deterioration of books on the perimeter due to ultraviolet (UV) light exposure from the north façade.

This study aimed to provide a wider view and understanding of the archive's performance. The goal was to examine the building's ability to provide a preservation level environment using both quantitative and qualitative methods. Based on initial observation and interviews, it was hypothesized that the archive was subject to inadequate air circulation, uneven temperature distribution, wide fluctuations in relative humidity, and unacceptable levels of indoor air pollutants.

2 Materials and Methods

This study utilized the quantitative research methods of experimental and numerical analysis and qualitative methods in the form of interviews and observations. Because the onsite research was limited to one week, focus was placed on the library's stacks and surrounding gallery. The stack area was chosen because it housed a majority of the collection. Figure 1 shows the floor plan of the test area. The stacks are an enclosed area separate from the surrounding gallery but share the same environmental control system that conditions the rest of the building.

While physical data collection is essential for obtaining actual measurements of environmental variables inside the stacks and gallery, they only provide a limited view of the indoor conditions. Therefore, numerical analysis using the computational fluid dynamics (CFD) software FloVENT by Mentor Graphics Corp. was employed in addition to the experimental data collection. Using the measured data and physical attributes of the archive, a numerical model of the environment was created that allowed one to view the temperature and ventilation performance of the entire volume of space three dimensionally. By using CFD, analysis of the environment was no longer limited to the number of sensors and the relative areas surrounding them.

Over a one week period during the spring, environmental variables were measured and monitored inside the stacks and gallery. Air velocity and air temperature were taken at the supply and return grills with a Pacer Instruments Inc. Hygro-Thermometer Anemometer HTA4200. Six Onset Computer Corp. HOBO U12-012 data loggers placed 122 cm above the floor measured air temperature, relative humidity, and light levels every 5 min. Fine particulates were measured using a TSI

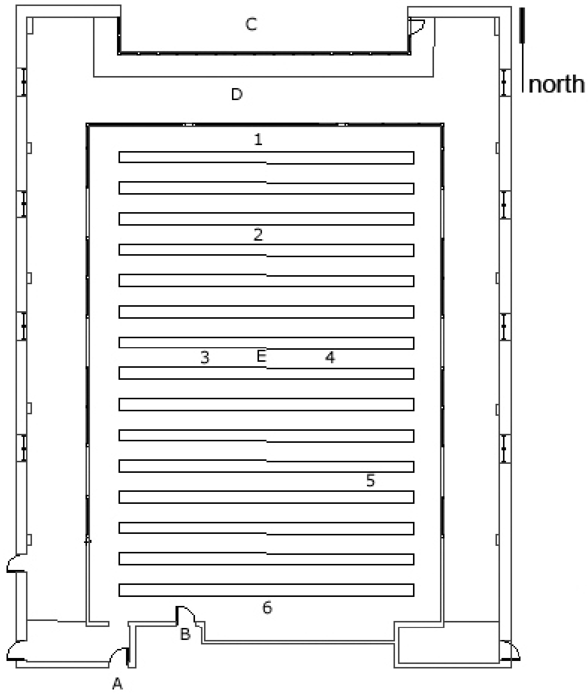

Figure 1: Floor plan of library stacks and gallery. 1-6 sensor locations, A - security entry, B - stairwell, C - balcony, D - reading room /gallery, E - stacks.

equipment	variable	accuracy	resolution	response time	manufacturer / location
HTA4200	relative humidity	±2% RH ±1 digit	0.1% RH	90% in 15 sec.	Pacer Instruments Inc. / New Hampshire, USA
	temperature	±0.2% of reading ±1 digit	0.1 °C	1 min.	
	airflow	±1% of reading ±1 digit	0.01 m/s		
HOBO U12	relative humidity	±2.5% from 10% to 90% RH	0.03% RH	90% in 1 min.	Onset Computer Corp. / Massachusetts, USA
	temperature	±0.35 °C from 0 °C to 50 °C	0.03 °C	90% in 6 min.	
8520 DustTrak	aerosols		±0.1% of reading or ±0.001 mg/m^3		TSI Incorp. / Minnesota, USA

Table 1: Specifications of measurement equipment.

Figure 2: Formaldehyde and VOC samplers hung from light fixture.

Incorp. DustTrak Aerosol Monitor which measures particle sizes ranging from 0.1 to 10 µm. The DustTrak measured the concentration in the air and gave average, high, and low readings for the one week measurement period for concentrations corresponding to PM2.5. Table 1 lists the performance specifications of the measurement equipment. Some passive and active samplers were used to sample air for mold, volatile organic compounds (VOC), and formaldehyde (Figure 2). These air samples were analyzed by a third party laboratory, Air Quality Sciences in Atlanta, Georgia USA. In addition to the environmental variables, data was collected on the building's design and construction (i.e. dimensions and locations of supply and return grills, shelves, light fixtures, building material, etc.). An infrared thermal imaging camera was also used to measure the surface temperatures of the archive (building structure).

Interviews were conducted with the staff and campus facilities management to collect information on the facility's usage and maintenance. Observations were carried out as part of the visual inspection of the building's environmental control system.

3 Results and Discussion

3.1 Experimental Analysis

The measured indoor pollutants, air temperature, and relative humidity within the archive were compared against the recommended levels set by the National Archives and Records Administration (NARA),[1] the National Information Standards Organization (NISO),[2] and the Library of Congress.

Analysis of the environment showed ozone (O_3) at 1.77 ppb and nitrogen dioxide (NO_2) at 0.65 ppb which were both under the limits for archives and human health. Sulfur dioxide (SO_2) was at 0.74 ppb, within NARA and NISO guidelines. But it was above the 0.38 ppb limit of the Library of Congress. Formaldehyde (H_2CO) was measured at 39.6 ppb, acceptable from a human health perspective. 50 ppb is generally considered the maximum for a healthy environment. However, from a preservation standpoint, levels were far beyond NARA guidelines of only 4 ppb. Because a small portion of the collection's books contain metals as part of the binding, the high ppb count can cause accelerated deterioration of the material. Total volatile organic compounds (TVOCs) were measured at 642 µg/m. That was above the 500 µg/m level for human irritation and discomfort. At 642 µg/m, it was approximately twice the targeted 300 µg/m level for indoor air.[3] Fine particulate filtration was calculated at 80% for a concentration of 0.045 µg/m^3, insufficient compared to NISO (90-95%) and Library of Congress (90%). Air samples also found evidence of soil based mold spores.

By comparing the measured average concentrations of the pollutants to Tetreault's[4] table of pollutant levels for museum, gallery, library, and archival collections, one can estimate the length of time before a collection begins to show effects from the pollutants. Based on the measured data, this archive was estimated to have a preservation targeted life of less than ten years. So within ten years, material stored in this environment would begin showing noticeable signs of deterioration.

Air temperature and humidity levels were a significant problem. The one week of measurements showed a temperature range of 20.7 to 22.3 °C. Temperature exceeded the maximum recommended by NARA (18.3 °C), NISO (18.3 °C), and the Library of Congress (10 °C ±1.4 °C) by 2.4 to 12.3 °C. Relative humidity ranged from 39.2% to 56.4%, a difference of 17.2%. This was significantly larger than the maximum 5% change recommended by the other archives. Furthermore, the high of 56.4% far exceeded the limits of NARA (35-45% ±5%), NISO (30-50%), and Library of Congress (30% ±5%).

The humidity level needed to be lowered but by no more than 2% per month to prevent paper from cracking and becoming brittle.[5] The air temperature should be lowered to 15.6 °C ±1.4 °C to meet

NARA and NISO guidelines and still remain at an acceptable level for human comfort since the archive is accessed by people throughout the day.

It is important to note that the physical data collected over the one week period (single continuous measurements of variables) is insufficient to assess the overall indoor environmental conditions of the archive. Long term monitoring of the environment is required to understand the impact of changing seasons and archive usage on the indoor environment.

3.2 Numerical /Computer Simulation Analysis

Computer simulation of the stack's indoor environment showed uneven distribution of air temperature and ventilation. Figure 3 shows the temperature distribution (left hand side column) at two heights. Based on the CFD results, air temperature was higher on the north end than the south end of the stacks. The right hand column images show ventilation effectiveness using local mean age of air (LMA). Results indicated LMA to range from about 10 min (blue) on the north side to about 33 min (orange) on the south side. The uneven distribution of air in the existing condition was primarily a result of the return grills being concentrated on the north end.

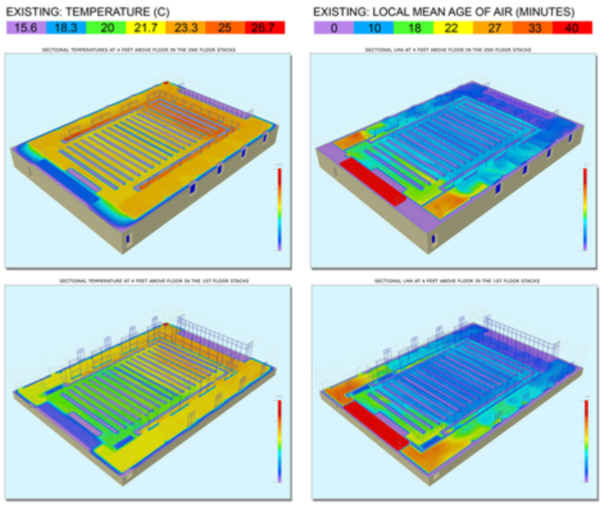

Figure 3: CFD images of existing conditions (top row shows second floor stacks and bottom row shows first floor stacks).

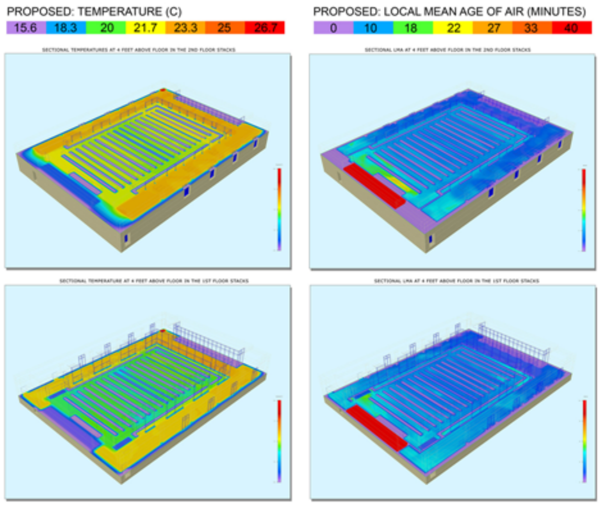

Figure 4: CFD images of proposed conditions (top row shows second floor stacks and bottom row shows first floor stacks).

Based on the CFD results of the existing conditions, modifications were made to the CFD model to address the uneven performance issues. By more evenly redistributing the existing supply and return grills, in particular placing return grills on the south side, both air temperature and LMA resulted in more even distribution (Figure 4). Although, contaminants were not simulated during this portion of the study, the LMA analysis gives an indication of how well or poorly an area of the archive would be ventilated and therefore diluting the pollutant concentrations.

By utilizing CFD, the entire volume of the study site could be analyzed in a time efficient and cost effective manner. It also allowed easy testing of different configurations of the supply and return grills based on the existing conditions. If used throughout the design process of an archive, computer simulation tools such as CFD can help significantly minimize potential environmental performance short comings before construction and occupation of the building.

3.3 Interview and Observations

Based on interviews with the archive staff and campus facilities maintenance, it was learned knowledge on the operation of the building was not shared at an appropriate level. The staff did not receive any detailed information on the environmental performance of their building and therefore had to conduct their own monitoring of air temperature and relative humidity using data loggers. Facilities recently spent $100,000 USD on upgrading the heating, ventilating, and air-conditioning (HVAC) control system including monitoring capabilities but the archive staff was not involved in that process. Nor were any of them aware of what work was performed or who and how the monitoring was being utilized. In this case, it would have been beneficial for the staff to be involved or at least made aware of the work so they could provide very knowledgeable input on the needs of a conservation level environment. The campus facilities management does not have this specialized knowledge in their department.

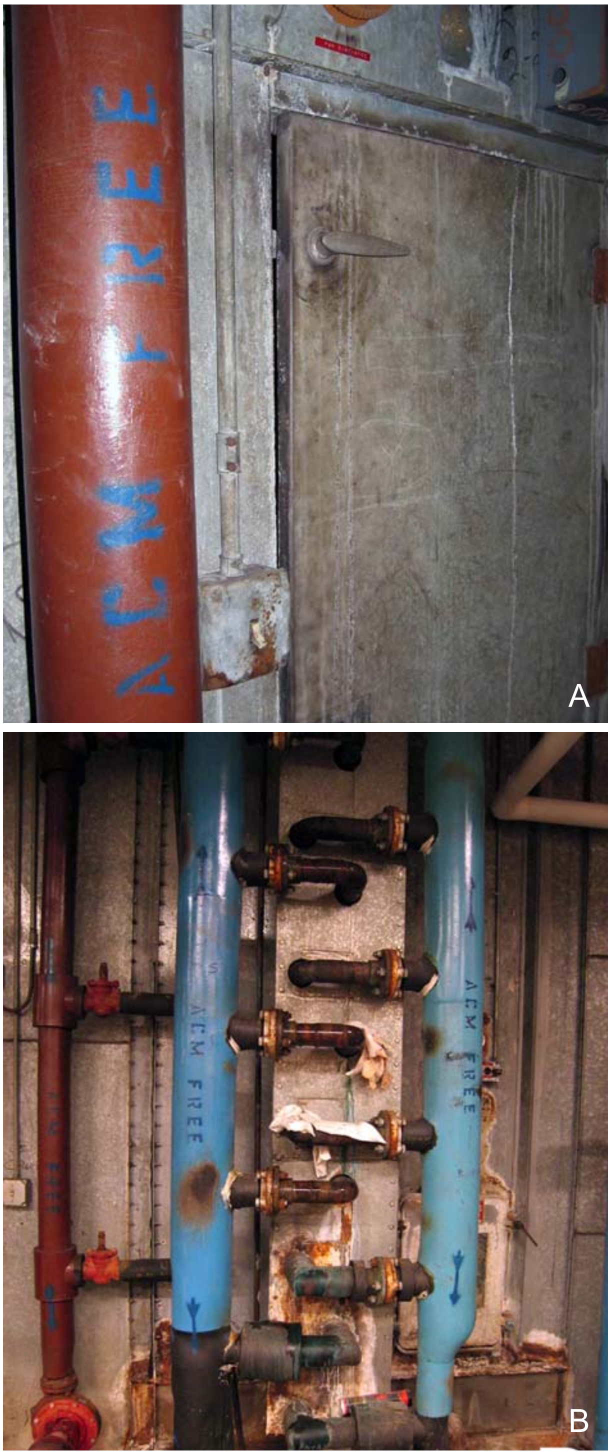

Figure 5: Images of air handling unit showing (A) bent access door with missing seals and (B) cooling coils with missing seals replaced with cotton rags.

It was also learned from facilities that the mechanical system was the original from 1968 when the building was built. Furthermore, it is the oldest building on campus yet to undergo major renovation. The filters were of a low Minimum Efficiency Reporting Value (MERV) rating, same as those used in other campus buildings which are primarily classrooms and offices. Such spaces do not require the level of filtration of an archive. This is one of the causes for having only an 80% filtration rate. The archive staff were unaware nor had any input on how often or what type of filters were replaced. While the existing filters could be replaced with high performance filters such as high efficiency particulate air (HEPA) filters, it should be checked with a mechanical engineer to make sure it will not cause a drop in pressure within the HVAC system. However the standard filters could be replaced with fiberglass/potassium permanganate filters or pleated filters as a simple but temporary solution[6].

Interviews also revealed that the mechanical system was without backup power. This omission became an issue a couple years ago when a storm disrupted campus power for a couple days. During this period without an operating mechanical system, the humidity level in the archive rose from around 50% to 80% in less than twenty four hours. Also the condensation that occurs in the gallery during the fall and winter was caused by the architect specifying exterior windows without a thermal break in the frames. The deterioration of books along the perimeter due to UV light exposure is a result of windows not having proper UV light filter applied to them. If a conservator was part of the design process, this particular issue could have been caught and addressed before construction.

Visual inspection of the building showed great deal of neglect and lack of understanding of how important it is to maintain strict environmental performance guidelines for archives. Figure 5 shows the effects of neglect and poor maintenance of the mechanical system. Figure 5A shows the access door of the one and only air handing unit (AHU)

Figure 6: Image showing fresh air intake grill located very near vegetation and damp soil.

bent with missing seals. The opening at the upper left hand corner of the door causes cold conditioned air to leak into the mechanical room causing condensation to occur around the equipment. Figure 5B shows the cooling coils of the AHU with missing seals. Instead of properly resealing the points of penetration, cotton rags are used to fill the gaps. This also causes a good deal of condensation and corrosion on the equipment as shown by the rust in the image. The wet cotton rags are also a potential source of mold growth. The condensation in the mechanical room is a possible contributor to the high fluctuation in relative humidity.

Figure 6 below shows the location of the fresh outdoor air intake grill. It is situated very near ground cover vegetation on the north side. Because of its orientation and the building to the south, the surrounding area is always in shade and the ground damp a good portion of the year. Combined with the poor performing air filters, this is a possible source of the soil based spores found in the stacks.

Although the building was originally designed as a state-of-the-art archive environment in the late 1960s, today its environmental performance is in a state of distress, unfit for archival needs. This downturn in performance is contributed by three main issues. First, the buiding and energy codes/guidelines in the late 1960s were less stringent then they are today. An example of this are the exterior windows without thermal breaks in the frame which lead to temperature fluctuations, severe condensation, and increased indoor humidity levels. Second, the entire library was designed to operate as a single indoor environmental zone. This resulted in compromising the more stringent archive environmental conditions with those for human thermal comfort. Third, facility maintenence lacks expertise in archive environments and has provided improper maintenance as evidenced by the findings in the mechanical room.

4 Conclusions

This pilot study showed that employing both quantitative (experimental and computer simulation) and qualitative (interviews and observations) research methods helped to give a broader view of a building's environmental performance. Based on the findings, it is important to test out an archive's design before construction to address any potential performance issues. Correcting problems during or post construction can be very costly. Also, conservators and preservationist must be involved in providing input to facilities management because the highly specialized knowledge of archive environmental needs lie with them, not mechanical engineers. This is also the case during the design stage. Knowledge must be shared across disciplines when dealing with such specialized environments. Architects are knowledge about the design of buildings, engineers with the construction and building systems, and preservationists and conservators with the needs of the collection. Without collaboration, archives cannot be designed and maintained to uphold conservation level environmental control.

5 Acknowledgements

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