Use of Controlled Ventilation and Heating for Preservation of Both Collections and Historic Buildings

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1. INTRODUCTION

The longevity and durability of organic collections (such as woods, papers, parchments, leathers, and textiles) in cultural institutions is known to be directly related to the surrounding environment, and especially sensitive to high levels of temperature and relative humidity which can accelerate chemical aging. Large variances of other environmental conditions (light, pollutants, particulates) can cause mechanical damage to collections as well [1, 2, 3].

In addition to these types of deterioration, collections located in hot and humid regions are often threatened by attacks of insects, fungi and bacteria where these conditions promote their growth. In fact, the risk of collection loss due to biological infestation is far greater than those risks posed by chemical aging and mechanical damage.

In the past, toxic fumigants and disinfectants were widely used to curtail biological infestation. However, due to increasing global environmental regulations as well as for the health and safety of those who treat collections, the focus has gradually shifted from treatment-based to prevention-based conservation approaches. Consequently, new, safer methodologies have been developed to replace chemical treatments, which are proving to be just as effective at lower cost and without health risk.

We have found that insect and other bacterial damage control can be achieved by implementing a suitable integrated pest management (IPM) program in museums and cultural institutions where such problems exist. By improving the collection environment (i.e., maintaining the RH to less than 75%), it is possible to halt and discourage further microorganism attacks.

Prior to this methodology, managers of cultural collections in hot and humid zones had installed sophisticated air-conditioning systems using rigid environmental specifications. But research and experience have since proved that, as is often the case in museums housed in older buildings, the superstructure and interiors of buildings may not withstand the installation and operation of these systems.

While air-conditioning systems do control temperature, relative humidity, insects and pollutants, they are often intrusive to the building fabric as well as expensive to install, operate and maintain. And, even if the system is custom-designed, there is no guarantee that it will produce the desired results.

Because of these issues, there has been a compelling need to find viable alternatives to air-conditioning systems that are economically sustainable, robust and technologically simple to operate. The present study was initiated in response to these needs.

In this study, conducted in three phases, we examined the efficiency of mechanical, non-invasive ventilation and space heating for museums and archives housed in historic buildings in hot and humid regions. The goal was to reduce and stabilize the level of RH to avoid bio-deterioration.

In the first phase, we conducted a series of laboratory experiments to establish the climatic conditions necessary to arrest fungal and bacterial activities typically found in collections in museums, libraries and archives. The parameters studied were temperature, RH and rates of ventilation.

In the second phase, conducted concurrently with the first phase, we reviewed practical climate control schemes for museums housed in historical buildings and evaluated the performance of several of the approaches [4, 5, 6].

The third phase, on which the present publication is based, dealt with the application of recommendations produced by the previous two phases of the project. From our results, we designed and installed climate control systems in two historical buildings located in hot and humid regions.

The efficacy of these control designs was evaluated through monitoring both the climates and microbial activities in the buildings. Two distinctively different buildings in two subtropical sites were selected for the experiment so that the same concept would and could, in fact, successfully apply to more than one situation.

The first historic building was Hollybourne Cottage, a 100 year-old, three and one-half story, tabby concrete building located in the Jekyll Island Historic District, on the Atlantic coast of the state of Georgia in the United States.

The second building was the Historic Archive, part of a massive municipal building constructed out of local volcanic tuff located in the historical district of La Laguna on Tenerife Island, Spain. This article describes only the research conducted at the Historic Archive, in collaboration with the Ayuntamiento de San Cristóbal de La Laguna and the Instituto del Patrimonio Histórico Español.

1. THEORY

The first step in the proposed preservation process was to understand the climate of the site and the preservation history of both the historical building and its collection. The second step was to establish environmental requirements and parameters for their preservation as a whole. And finally, the third step was to develop strategies to prolong the longevity of both the building and the collection.

Following these steps, climatic conditions in buildings will be improved, preventing decay of both building and collection materials. And, this improvement will be achieved by avoiding major alterations of the building fabric or design; re-activating and improving the original (passive) building ventilation features, all while adapting the least invasive electromechanical climate systems.

In tropical and subtropical climates, moisture content in the air remains fairly constant throughout the seasons (rainy and dry). Daily temperature variations range from less than 5° C in the rainy season to more than 15° C in the dry season. These temperature variations in turn produce inverse variations of RH. For example, a 1° C rise of air which is 25° C and 80% RH can result in a 5% drop of RH.

Although it may seem that a climate is hot and humid at all times, it is actually always cooler when higher humidity (foggy or raining) is recorded outside. Similarly inside buildings, areas of higher humidity are found in cooler parts of the building (providing water infiltration is not the direct cause).

The proposed approach, then, to improve the climatic environment in historic buildings in such conditions, was to raise the temperature in cooler areas of the building, rather than cooling the air to below its dew point temperature in an effort to remove the moisture (and then re-heating it). Increasing temperature causes a necessary reduction of the RH level, subsequently causing a reduction of microbial activity. The ideal is to maintain RH for the collection environment at less than 70%, slightly (5%) less than the threshold RH for significantly increased microbial activity [7].

Heating a building's interiors can be achieved either by using space heaters, or by bringing in warm and (therefore) dry outside air using mechanical ventilators, assuming passive methods don't produce sufficient ventilation. This strategy not only maintains an environment that arrests microbial activities, but also raises the surface temperature of cooler surfaces of the building.

By reducing the difference between moisture contents in the air both inside and outside the building as small as possible, the translation of moisture (water) in building fabrics can be avoided. In addition, reducing the uncontrolled air infiltration of the rooms, combined with the moisture reserve of the documents, is used to limit low RH conditions.

We will equilibrate environment throughout all rooms in the building to eliminate cool (therefore damp) spots. This can be achieved by installing a fan to produce sufficient air movement and rearranging objects to allow enough air movement in display and storage areas.

2. BUILDING AND METHOD

For this study, we selected a historic building in a subtropical region of Spain, as it was representative of a typical construction in both Central and Latin American regions. Our criteria for selection were that the building had to be made of either the brick or stone masonry (as are most surviving historical buildings in these regions) and that there was evidence of moisture problems contributing to microbial activity in both the building and collections. A third consideration was that the building did not present basic maintenance issues.

In the first year of the study, climates of the building and surrounding site were monitored, allowing us to define initial climate settings of both areas. Based upon this information collected from monitoring, a climate control system was designed and installed. Afterwards, we evaluated environmental changes made by the system and the consequent improvements to the building and collection.

3.1 General Climate of the Site

The building chosen for the study was the Historic Archive of the municipality of San Cristóbal de La Laguna (N28º 29.012', W16º18.905', 505 m above sea level). This historic city is located in the north side of Tenerife Island, one of the Spanish Canary Islands off the cost of Morocco. UNESCO nominated this historic district as a World Heritage Site in 1999.

The city of La Laguna is known to have a mild but humid climate throughout the year that can be classified as the sub-tropical of type Csb, according to Köppen's classification. Light westerly sea breezes are present on the island throughout the year. Significantly higher monthly rainfalls have been recorded in November through March, although rain can fall year-round with an annual average accumulation of 600 mm.

Summer begins in June and ends in October, but August is the hottest month, with an average temperature of 20.3°C and average RH of 73%. Daily temperature and RH variations are more noticeable during the hot dry months, the averages being 7°C and 30% respectively.

Winter begins in November and ends in March, but it is only noticeable when snow covers the highest island mountain elevation (3,718 m). January is the coldest month, with an average temperature of 13.6°C and average RH of 79%. During the cold wet months, daily temperature and RH variations are smaller than in summer, the averages being 4°C and 15% respectively. The annual mean temperature and RH values in the 30-year record, were 16°C and 75% RH respectively [8].

3.2 The Historic Building under Investigation

The Historic Archive is housed in a late 19th century building that originally belonged to the Dominican Nuns. It is a two-story building with an above-grade basement that surrounds a patio (Fig. 1).

Figure 1: Façade of the Ayuntamiento de La Laguna complex with its three historic buildings. The first one on the left is where the Historic Archive is located.

In 1975, the Ayuntamiento (City Council) de San Cristóbal de La Laguna acquired the building. It was refurbished in 1985 to accommodate some offices of the municipality. Among them was the Archive, which now comprises about four rooms housing historical documents of the Canary Islands. The refurbishment kept the façades and most of external walls intact (about 40 cm thick), but the majority of internal partitions were removed to allow for more spacious rooms.

The majority of exterior doors and windows were permanently closed to provide security and protection against outside forces, including the intrusion of animals and insects. These modifications however, altered the original ventilation features of the building, creating many pockets of still air. These stale air pockets forced the staff to use dehumidifiers to control high RH levels in an effort to arrest microbial activities.

3.3 The Area of Investigation

The Historic Archive, located at the west corner of the building, consists of two rooms (6.6 m x 3.2 m with ceiling height of 2.3 m; and 1.7 m x 2.5 m with the ceiling height of 4.0 m) connected by a door (2.4 m high x 0.9 m wide). Entry is made through a normally closed door (2.4 m high x 0.9 m wide) into the smaller of the rooms (Fig. 2). Although access is limited, archivists enter the rooms daily.

The smaller room had a northwest-facing window (0.6 m x 0.5 m) at 2.5 m from the floor, and the larger room had a 0.7 m x 1.14 m window facing the southwest, but both were permanently closed for security and environmental reasons. A two-meter high steel shelf was affixed to the two longest walls, and smaller movable shelves covered other walls, including windows. All shelves were filled with archival documents. Most of the documents were unbound and placed in document cases made of acid-free paper or polypropylene.

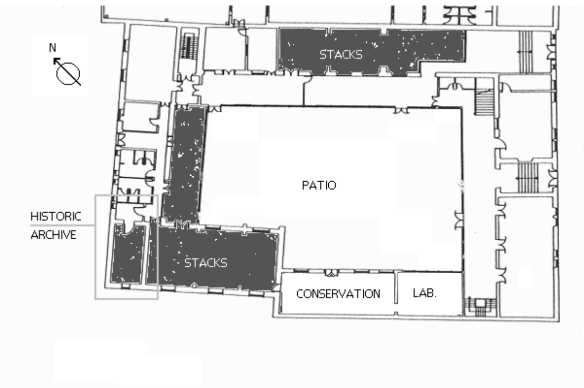

Figure 2: First floor plan of the municipality building, showing the rooms where the stacks are located (gray areas), the patio, the conservation laboratory, and the two rooms where the alternative climate control system was installed (highlighted by a rectangle).

3.4 Environmental Monitoring

An autonomous environmental monitoring station [9] was installed in the larger room of the Historic Archive in May 1999 to characterize the climate in the rooms as well as to evaluate the efficacy of climate control strategies once they were installed. Monitored parameters were:

- air temperature and RH, both inside the room and outside the building
- surface temperatures of the ceiling and floor (to map the stratification of the microclimate or temperature gradients within the rooms)
- surface temperatures of documents in the document cases, and
- air movements.

These environmental data were periodically downloaded through a telephone line to a personal computer at the Getty Conservation Institute in Los Angeles, USA, for analysis.

3.5 Climate Control System

The climate control system, installed in the Historic Archive in May 2000, consisted of a set of supply and exhaust fans for ventilation, and a set of agitator fan and a convective heater for heating the rooms. We also made a slight modification to the entrance area (as described below and shown in Fig. 3). The ventilator set-up was designed to produce 6-8 air changes per hour. The heater (rated 1.5 kW) was selected to produce an increase of only few degrees in the space. These items were all off-the-shelf residential use equipment.

An anti-microbial filter and a gravity-operated shutter were placed with the supply fan for controlling the quality of the fresh air and to limit the amount of infiltrated air through the fan. The exhaust fan was also equipped with a spring-loaded shutter that opened only during fan operation. These fans were placed in the existing windows at the two ends of the connected rooms to provide cross ventilation in the space. The heater and agitator fan were mounted on a wall and ceiling, respectively, segregating the rooms. They were operated together to avoid localized heating and to distribute the heat as evenly as possible in the space.

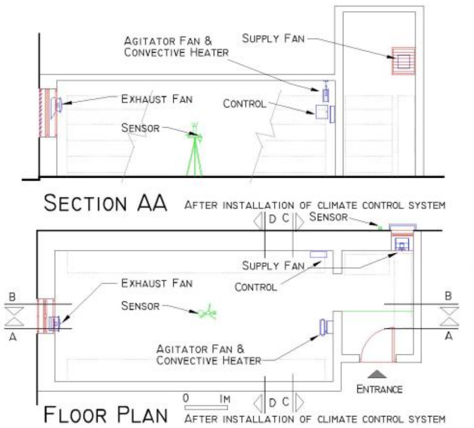

Figure 3: Plan and cross section of the two rooms where the alternative climate control system was installed, showing where the mechanic units and sensors are located.

These fans and the heater, along with two (RH and air temperature) sensors--one in the center of the room and the other just outside of the building--were connected to a programmable controller [9]. The controller activated the ventilator whenever the outside RH was below 70% and the inside RH was higher than 70%. The ventilator ran until the inside RH was reduced to 65% or less.

The small heater/agitator fan was activated when both external and internal RH levels were above 75%. The heater ran until the inside RH was reduced to less than 70%, or the outside RH had fallen below 70%, at which time the ventilator would activate.

3.6 Other measures and measurements

A workshop-type curtain consisting of overlapping thick vinyl strips was hung from a reduced ceiling to control the air change at the entrance. The curtain, designed for the limited available space, allowed for the daily access of archivists.

A steel door segregating the two rooms was removed to enable cross ventilation and good air mixing. Since the majority of the shelves were affixed to walls, only the movable shelves were relocated. The majority of gaps in windows and doors were filled with oil-based putty (an off-the-shelf weather stripping material) to reduce outside air infiltration.

Since ventilation was the primary tool used to control RH levels, particulate matter was also monitored during the study using the quartz crystal micro-balance technique. In this process, a quartz plate is exposed to the environment for a period of two months and then weighed.

Microbial activities both in the environment and on documents were monitored monthly, both before and after installation of the climate control system [10]. To identify fungal activities as well as species, air samples as well as surface samples were collected at three locations, near the entrance, in the middle, and near the deepest location of the rooms, and impacted or physically transfered on culture media including czapeck, saboreaud, malta agar and cellulose agar, and they were incubated at temperatures, 25°C and 28°C for 15 days.

3. RESULTS

Figure 4 shows temperature and RH values measured outside the building, plotted on a psychrometric chart. Annual temperature means were identical at 17.1ºC, and RH means were 77.5 and 80.4% in 1999 and 2000, respectively. Typical daily variations were 10ºC and 30% RH.

This climatic pattern was erratically disturbed by Saharan winds (strong southwesterly winds originating in the Sahara Desert), raising the temperature (maximum of 38.16ºC measured on July 3, 1999) and lowering the RH (minimum of 12.28% on November 9, 1999).

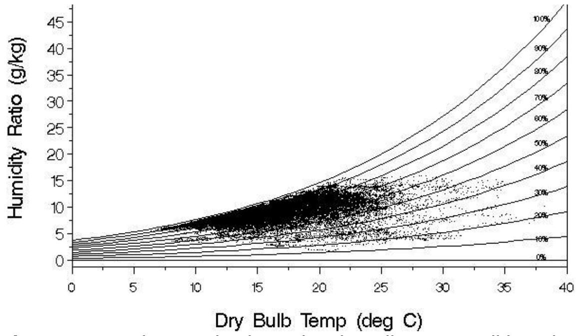

Figure 4: Psychrometric chart showing climate conditions in La Laguna, Tenerife Island. Each data point represents a 15-minute reading.

The inside temperature was very stable, as expected for a massive building, with an annual average of 19.5ºC (a maximum of 24.5ºC and minimum of 14.8ºC). In the Historic Archive, the standard deviation was only 2.4ºC prior to the installation of our climate control system. Histograms of the room's temperature and RH are shown in Figures 6 and 7.

The annual indoor RH average was 68%, below the level for fungal germination, with a standard deviation of 4.1%. 9% of the measurements were recorded above 72.5% RH, and 1% fell below 57.5% RH. From an Archive conservator's general observation, the room was generally cool and damp (with a maximum RH of 84%) and carrying a strong musty mold smell. However, during periods of Saharan wind, we registered a brief RH drop to a minimum 48%, indicating that the collection was exposed to a large humidity cycle.

Probably due to the relatively low ceiling height of only 2.3 m, a temperature difference of less than 1ºC was recorded between the floor and ceiling. The room's annual average of humidity ratio was 9.6 g/kg of dry air, slightly higher than that of the outside, 9.3 g/kg. This fact indicates that both the rooms and documents retained moisture that was absorbed during high RH.

Figure 5 shows climates of both in the Historic Archive and the outside of the building during the second half of January 2001. In this period, three typical climatic events occurred while the climate system was operating.

It possibly rained on January 15th-16th, with the outside RH remaining at nearly 100%. During the two-day event, the Archive's interior RH was successfully maintained at less than 75% by heater activation, resulting in a temperature increase of only 1.3°C (from 16.5 to 17.8 °C).

A period between January 17th and 22nd was clear days, and the interior RH was maintained at safe levels by operating the ventilator. The ventilator was activated from approximately 12-6 PM, at which time the outside RH dropped to less than 70%, and the ventilator was deactivated once the RH inside the building reduced to less than 65%.

On the 23rd and 24th, during the Saharan winds, the climate system deactivated both the ventilator and heater. While the outside RH dropped to 20% (January 23, 2001, 5:30 PM), a low air infiltration rate combined with the moisture content of archived documents to maintain 60% RH in the room. And the large thermal mass of the building kept the room's temperature at 16.6°C when the outside temperature rose to 24.7°C (January 23, 2001, 4:30 PM).

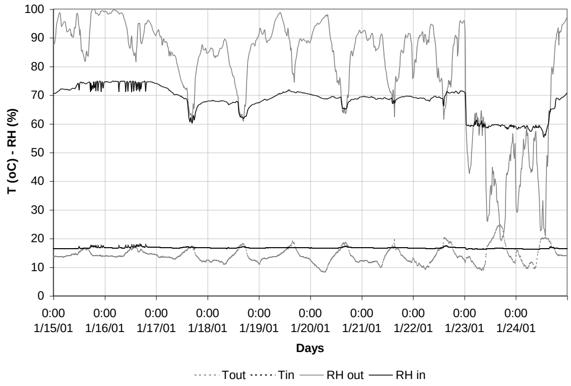

Figure 5: Operation of the climate control system installed in the Historic Archive, in the second half of January 2001.

Although the annual mean values of room temperatures recorded before and after the installation of the climate system were similar, at 19.5°C and 19.6°C respectively, the distribution was noticeably changed after installation (Fig. 6). Occurrences of both low and high temperature events were significantly reduced, and temperature was confined to a narrower range.

The annual RH average slightly decreased from 68% to 67%. However, more importantly, we successfully managed to keep the RH to less than 75% at all times. Less than 4% of the measurements were higher than 72.5% RH (Fig. 7). The minimum as well as the distribution of low RH values were also unchanged, indicating that our effort to limit air infiltration was successful.

The annual average of the indoor humidity ratio was 9.4 g/kg of dry air, less than that of the outside (9.6 g/kg of dry air). This indicated the successful reduction of the moisture content in the rooms. Although slight reductions of surface temperatures were observed, they followed the temperature of room air. And the temperature difference between the ceiling and floor remained unchanged.

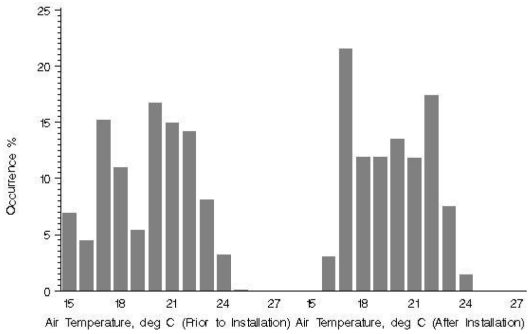

Figure 6: Distribution of air temperature values, before and after installation of the alternative climate control system in the Historic Archive.

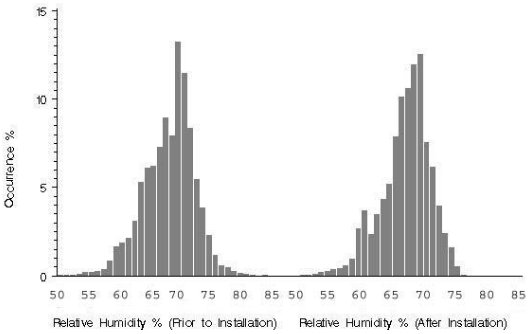

Figure 7: Distribution of relative humidity values, before and after installation of the alternative climate control system in the Historic Archive.

Dust deposition increased just after the installation of the climate control system, and then stabilized to a small value (14.6 ng/day). We assume that a large amount of dust was generated during the installation and became settled over time, and no new dust was introduced to the room. This result is attributable to filtered fresh air being used for ventilation coupled with limited air infiltration in the rooms.

Penicillium comune, Aspergillus niger, Aspergillus sp, Cladosporium herbarum, Cladosporium fulvum, Penicillium comune, Trichoderma viride, Rhizopus nigricans, Fusarium roseum, Stachybotris atra and Mucor sp. were identified to be common fungi in the Archive. Most of the fungi are significantly active in cellulotic environment. For this reason a potential risk of deterioration exists, especially in the case of possible changes of environmental conditions. And *Aspergillus niger* is a potential pathologic organism for humans. Most of bacteria identified in the Archive belonged to the genera: *Bacillus subtilis, Bacillus cereus Micrococcus luteus, Actinomyces sp.* Both their populations were very low levels and activities were stable during the months.

Microbial monitoring has also proven the efficacy of climate control through reduced numbers of colonies (CFU) from air sampling, although those on paper surfaces remained unchanged [10]. This can be explained by the fact that, unlike environmental sampling, the determination of microbial activities on a surface is difficult. It is also possible that the environmental improvement had not yet impacted the documents in boxes (micro-environments) in the given testing period.

4. CONCLUSIONS

The concept of an economically sustainable and technologically simple climate control system for preserving both historic buildings and their collections in hot and humid regions was tested in the Historic Archive of the municipality building of La Laguna on Tenerife Island, Spain.

Prior to the installation, environmental monitoring was conducted for a period of twelve months to characterize climates of both the archive room and the outside of the building. The city's climate was identified as mild in temperature but very humid. The massive stone building provided a thermally stable environment. However, the outside highly humid air combined with a high air infiltration rate of the building, and the tendency of both documents and the building fabric to retain moisture, had caused several periods of high interior RH, resulting in high levels of microbial activities in the environment and on the documents.

A custom-designed climate control system, consisting of a humidistatically-controlled ventilator and heater, was installed in the Historic Archive, accompanied by a small amount of building modifications and furniture re-arrangements. After operating the system for nearly one year, the following conclusions were drawn to evaluate the performance efficacy as well as the sustainability of the system:

- seasonal variation of temperature was significantly reduced with no change in its annual average value
- no events where RH reached above 75%
- a significantly reduced number of events in which the RH reached above 70%
- significantly reduced humidity ratio that is less than that of the outside
- daily temperature and RH variations slightly increased
- dust deposition initially increased then stabilized to a low level
- environmental microbial count decreased while the surface microbial count of documents in boxes remained unchanged
- a predominant use of ventilation resulted in low air speed in the room
- significantly low energy consumption
- installation was possible with minimum building modifications
- the system is simple, cost effective and requires low maintenance.

The climate system successfully produced and maintained the proposed environmental condition of less than 75%RH at all times and less than 70% RH most of the time. We expect that a longer operation of the system will gradually reduce moisture contents of documents kept in boxes and, in terms, reduce microbial activity even on the documents. We anticipate that the system is capable of producing even a lower RH (65%) environment with a slightly elevated (less than 1°C) temperature.

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