CONTROLLED VENTILATION AND HEATING TO PRESERVE COLLECTIONS IN HISTORIC BUILDINGS IN HOT AND HUMID REGIONS

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Ventilator-heater based climate control systems were installed in two historic buildings, each located in hot and humid regions, for full-scale experiments. The systems have been controlled based on RH sensors located inside and outside of the buildings, Their environments have been monitored - before and after the installation and operation of the climate systems - to evaluate the design effectiveness. Less than 70% RH has been maintained. Dust depositions have increased as a result of air movement only, given that the supply air has been filtered. The microbial activity has been reduced significantly in one case. The installation of the systems and some modification in the buildings were very simple. The systems are completely automated and robust, and in one year of operation, there has been no need for maintenance or repair. The operation and the running costs of the ventilators and heaters have been documented during the study.

1. INTRODUCTION

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.

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

Cultural institutions in hot and humid zones have been installing air-conditioning systems primarily for human comfort (the comfort of occupants and visitors) but for their collections as well. However, research and experience have since proved that, as is often the case in museums, libraries and archives 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 properly 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.

THEORY

In tropical and subtropical climates, moisture content in the air remains fairly constant throughout the seasons (rainy and dry). However, daily temperature variations range from less than 5°C (9°F) in the rainy season to more than 15°C (27°F) in the dry season. These temperature variations in turn produce inverse levels of relative humidity. 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). Basements often have problems resulting from high levels of relative humidity; attics and upper floors suffer from heat accumulation and low levels of relative humidity.

The proposed approach, then, is to utilize the dry outside air, when it is available, to remove moisture accumulated in the building, or to raise the temperature in cooler areas of the building either by warm outside air or heating. The increase in temperature causes a necessary reduction of relative humidity in the building, subsequently causing an arrest or reduction of microbial activity. The goal is to maintain relative humidity for the collection environment at less than 70%, slightly (5%) less than the threshold relative humidity for significantly increased microbial activity (Brundrett 1990). By providing adequate ventilation and air circulation that can eliminate cool-spots in the building, we can reduce water activity numbers on the surfaces, arresting microbial activity (Valentín 1998).

Historically, buildings have been designed with various architectural features that can passively control their climate for the health and comfort of occupants as well as promote their longevity. However, as buildings age, various modifications can be made on their structural fabric; hence those original architectural features as well as operational considerations may no longer be as effective. Therefore, if the passive features don't produce sufficient ventilation, those can be augmented by an electro-mechanical mean, ie, dry outside air can be brought into the building using mechanical ventilators through an appropriate filter. Heating the building's interiors can be achieved either by using space heaters, or by bringing in warm and (therefore) dry outside air using the ventilators. Necessary mixing for an equilibrated room environment can be achieved by installing fans in strategic locations and rearranging objects in display and storage areas to produce sufficient air movement. This strategy not only maintains an environment that arrests microbial activities on the collections, but also raises the surface temperature (reduces the water activity number) of cooler parts of the building and prevents accumulation of moisture. We can simply exhaust the accumulated heat by opening vents or installing exhaust fans in higher parts of the building. These improvements can be produced without major alterations of the building fabric or design; reactivating the original (passive) building ventilation features while argumenting their performance by adapting the least invasive electromechanical devices. Operating residential or industrial-type ventilators mounted in existing windows and vents as well as convection heaters in open areas can achieve the desired results. These can be operated with a programmable humidistat control that make switching of the equipment based on an algorithm, determining the operation based on outputs of RH sensors located both inside and outside of the building.

2. METHOD

The climate control system is designed based on understanding climate in the building and the local climate. First, we will plot temperature and relative humidity data of the local climate on a psychrometric chart. From clusters of the data points we can characterize the local climate, then identify temperature and relative humidity conditions that are possible in building if the same outside air is maintained in the building.

We will, then, plot outside relative humidities vs. those of the inside the building. We can segregate regimes that require ventilation, heating, and none operation (static), by selecting a proposed relative humidity at which you propose to maintain in the building. If the inside relative humidity is less than the set value, the system will not operate regardless of outside conditions. However, if the inside relative humidity is higher than the set value, but the outside relative humidity is less than the set value, the dry outside air is brought into the building (ventilation). The heater is operated in the building to reduce the relative humidity, if both relative humidities inside and outside are higher than the set value. Values less than 75% RH are recommended as the set value in hot and humid regions for controlling microbial activities. However, the value has to be also selected for the minimum use of heating to besustainable.

Leaks of rainwater and seepages of groundwater seepages into the building have to be either eliminated or minimized. Large openings of the building envelope are sealed to obtain the control of climate by minimizing the infiltration of outside air and allowing both contents and building fabric to buffer changes of relative humidity. This will include treatments of entrance area (if the building has frequent entry and exit by staff members or visitors) by installation of vest view area. Pairs of (supply and exhaust) ventilation fans are mounted on existing windows in order to produce the most effective distribution of outside air with the minimum loss due to infiltration. Convective heaters or heaters with agitators or fans are install in the building to provide a good distribution of the heat.

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.

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

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 San Cristóbal de La Laguna (N28º 29.012’, W16º18.905’, 505 m above sea level) on Tenerife Island, Spain (sub-tropical of type Csb, according to Köppen's classification).

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3.1 Historic Archive

3.1 The Historic Building under Investigation

Figure 4 shows temperature and RH values measured outside the building of the Historic Archive, 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.

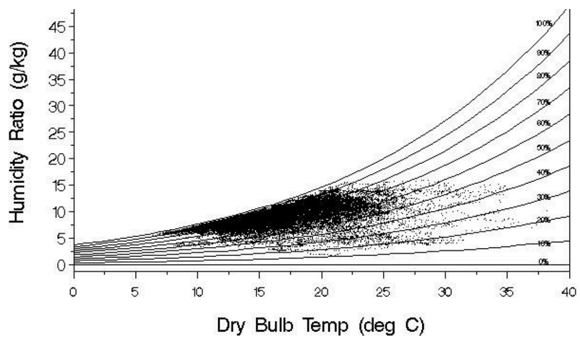

Figure 4: Psychrometric chart showing climate conditions in La Laguna, Tenerife Island . Each data point represents a 15-minute reading.

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. 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). Although access is limited, archivists enter the rooms daily. The staff has been using dehumidifiers to reduce high RH levels.

3.5 Climate Control System

The climate control system 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. These items were all off-the-shelf residential use equipment. We also made a slight modification to the entrance area.

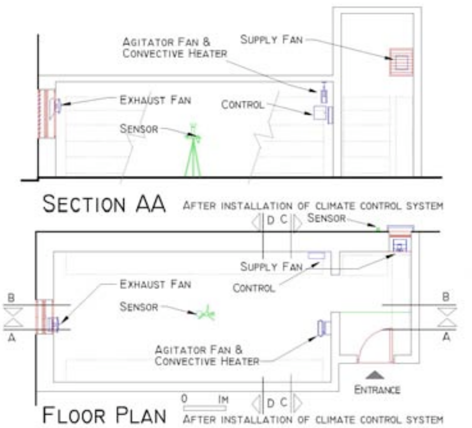

Figure 3: Plan and cross section of the two rooms where the alternative climate control system was installed, showing where the mechanic units and sensors are located.

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 and agitator fan were 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.

Results

Histograms of the room's RH before and after the installation of the climate system are shown in Figure 7. The annual indoor RH average was 68%, below the level for fungal germination. 9% of the measurements were recorded above 72.5% 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.

The annual RH average slightly decreased from 68% to 67% after the installation. 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. The minimum as well as the distribution of low RH values were also unchanged, indicating that our effort to limit air infiltration was successful.

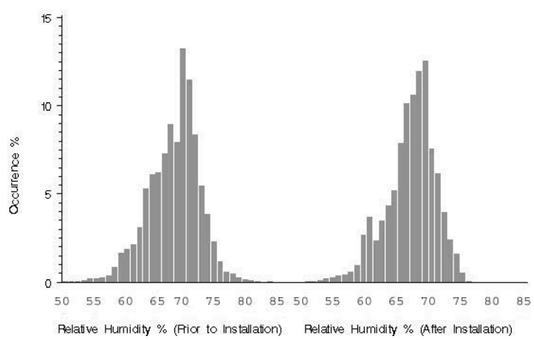

Figure 7: Distribution of relative humidity values, before and after installation of the alternative climate control system in the Historic Archive.

3.2. Hollybourne Cottage, Jekyll Island, Georgia (USA)

For second building, a historic house was selected in a subtropical region of the United States. Jekyll Island (N31°01’ latitude and W81°03’ longitude) is located on the Atlantic coast of Georgia. Hollybourne Cottage, a 'T'-shaped, two and one-half story with a full height basement, is made of faux tabby (concrete) walls and double brick foundation walls that carry the structural load. The interior of the building is made of wood. These floors are connected through two staircases: the large main stairway at the center of the building, connecting only the first and second floors, and the steep and narrow secondary stairway, starting in the basement and ending in the attic. The total floor area is approximately 1,068 m_ (11,300 ft_), with an air volume of 2,714 m_ (90,000 ft_).

Figure 2 shows the basement floor plan. Double brick foundation walls with an air gap create the basement boundary, about 2.44 m (8 ft) high. It has a concrete slab floor. The floor area is approximately 287 m_ (3000 ft_) and the air volume, 700 m_ (23,000 ft_). These walls have a total of 17 identical hinged (operable) windows. In the summer, the basement environment was near 100% relative humidity at all times, and a strong mildew smell filled the place.

The Climate Control System

The climate control system, installed in Hollybourne Cottage, consisted of sets of supply and exhaust fans for ventilating and convection heaters for heating the basement. The heaters were selected to produce an increase of only several degrees in the space. A programmable controller activated the ventilators whenever the outside relative humidity was below 70% and the inside relative humidity was higher than 70%. The ventilators ran until the basement’s relative humidity was reduced to 65% or less. The heaters were activated whenever both outside and inside relative humidity exceeded 75%. The heater ran until the inside relative humidity was reduced to less than 70%, the outside relative humidity had fallen below 70% (at which time the ventilator would activate), or when the air temperature in that space reached 30°C (86°F). This temperature was estimated based on the moisture ratios found in the basement during 1999.

RESULTS

During the summer, both ventilators and heaters in the basement were activated frequently. The ventilators operated during daytime (from about 10:00 AM to about 4:00 PM), and heaters warmed the basement throughout the night (from about 6:00 PM to about 8:00 AM). With these operations, relative humidity values in the basement were kept below 70% most of the time, while air temperature was kept below 30°C (86°F).

Table 1 shows a statistical summary of air temperature, relative humidity, and humidity ratio before and after the installation of the climate control system in the basement. In the basement, the mean temperature increased from 19.6°C (67.3°F) to 22.0°C (71.6°F). This temperature increase resulted in significant reduction of the mean relative humidity, from 84% to 65%.

Histograms of relative humidity before and after the installation of the climate control system for the basement are shown in Figure 7. In the basement, the major change in the temperature distribution was the addition of events for 27.5°C - 32.5°C, which was the largest occurrence.

3. 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 and Hollybourne Cottage in the Jekyll Island Historic District, Georgia, USA. Prior to the installation, environmental monitoring was conducted for a period of twelve months to characterize climates of both the buildings and the outside of the buildings.

The outside highly humid air combined with a high air infiltration rate of the building, cooler building interior, 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 buildings, 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%
- daily temperature and RH variations slightly increased
- dust deposition initially increased then stabilized to a low level
- environmental microbial count decreased

- 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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