

Climate Controls in a Historic House Museum in the Tropics: A Case Study of Collection Care and Human Comfort

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ABSTRACT: A climate control strategy that provides an alternative to a standard air-conditioning approach was designed in the library of Casa de Rui Barbosa Museum, a historic house museum located in Rio de Janeiro, Brazil. Based on condition assessments of the building, the collection, and the environment, climate improvement strategies were developed and implemented. The building envelope was repaired and original passive climate designs were restored. A ventilator/dehumidifier-based climate control system was installed in the cellar and attic, primarily for providing collection preservation in the library. Comfort for visitors was addressed through the implementation of a high air-exchange rate of the climate system and high air movement along visitor pathways. Energy conservation was incorporated through full ventilation during dry outside conditions (normally sunny afternoons), full recirculation, and hibernation modes during non-visiting hours. The installed system has maintained a climate of $60 \pm 5\%$ RH at $25 \pm 3^\circ\text{C}$ with reduced air pollution levels and particulate matters. Although the designed level of air movement was not achieved along visitor pathways due to difficulties encountered during the installation of floor grills, visitors have expressed comfort in the library due to lower humidity, a clean-air sensation, the elimination of direct sunlight, and low noise levels.

Keywords: house museums, historic buildings, energy saving, comfort

INTRODUCTION

Cultural institutions have historically used conventional air-conditioning (HVAC) systems as the primary means of climate control. While capable of moderating the environment for both collection preservation and human comfort, using typical HVAC systems can pose significant obstacles. Excessive capital, operational, and maintenance costs, and installation difficulties for historic structures are just some of the major issues. While the ability of a ventilation-dehumidification/conservation heating-based climate control strategy (an alternative to the conventional HVAC approach) to establish and maintain safe environments for collections in hot and humid climates in a technically simple and cost-effective manner has been confirmed through field trials [1, 2, 3], its capability to provide for human comfort while maintaining this environment has remained untested. If this strategy could also satisfy human comfort levels, the potential application of this low-cost, relatively simple and safe strategy, particularly for historic buildings and house museums, could be widely expanded.

With ten thousand visitors annually, the Museu Casa de Rui Barbosa (MCRB), an 18th century building with a 19th century interior in the busy Botafogo district of Rio de Janeiro (a nationally important historic building listed

by the Instituto do Patrimonio Historico e Artístico Nacional (IPHAN) and designated as Brazil's first house museum in 1930) provided an ideal venue for testing the applicability of the climate control strategy in a setting where human comfort was an important consideration. The Barbosa collection includes artwork, furniture, and several automobiles. However, the library collection—consisting of 37,000 books covering law, humanities, and culture—is considered to be the heart of the museum.



Figure 1: Historic interior of the library of Museu Casa de Rui Barbosa..

The library of MCRB (Fig. 1), located on the first floor of the 18th century masonry building, consists of five inter-connected rooms: Constitution Room, Civilest Room, Civil Marriage Room, Civil Code Room, and Corridor. The five rooms have a total floor area of 165 m² with a ceiling height of 3.8 m (approximate total volume of 630 m³). The rooms contain Rui Barbosa's original book collection in custom-built book cabinets, furniture, and artworks. Therefore, the Fundação Casa de Rui Barbosa (FCRB) considers them to be the most important rooms in the house and selected this area as the focus for the climate improvement project.

In 2004, a project was initiated between the Getty Conservation Institute (GCI) and FCRB with a goal of improving the house's indoor conditions, specifically providing human comfort within a stable and safe environment for the collections. This initiative was a unique climate improvement project for historic houses in Brazil in which the preservation of the collections and the building, visitor comfort, and sustainability were addressed in hot and humid climate regions.

METHOD

Mechanical deterioration, such as crack and deformation, can be controlled by providing a stable relative humidity environment for limiting their hygrometric dilatations. Chemical degradation, such as aging and oxidation, is considered to be less threatening in these regions, since the process is relatively slow, and the majority of collections have already reached chemically stable stages in stored and displayed environments. However, the process can be slowed by keeping the environment cooler, drier and darker. The biggest threat to collections in hot and humid regions is biodeterioration, and fungal and bacterial attacks. This can be controlled by maintaining the environment at less than 65% relative humidity.

The control of both the temperature and relative humidity is technically difficult and costly, especially in historic buildings in hot and humid regions; therefore, we focused our efforts on maintaining a stable range of relative humidity environment at less than 65% for protecting the collection from biological and mechanical deteriorations while allowing the temperature to vary. This method allows the climate control strategy to be both technologically simple and economically sustainable. Cooling of the library air was limited to only conditions above 28°C, when human comfort became significantly affected, and avoiding the possibility of condensation on the collection and the building.

It was important to maintain the historic ambience in the library, so that original aesthetic of the building (both the exterior and interior) had to remain intact. This

meant no alteration of walls and ceilings of the building. Since sustainable preservation environments for collections may produce higher than acceptable temperatures for occupants and visitors, we would provide higher air movements in the space to improve their comfort level.

Thermal comfort of occupants can be estimated based on: 1) metabolic rate; 2) clothing insulation; 3) air temperature; 4) radiant temperature; 5) humidity; and 6) air speed. The predicted mean vote (PMV) can be calculated from the above six parameters. Thermal sensations are defined from +2 (warm) to -2 (cold). Values between -0.5 and +0.5 are considered to be acceptable. [4] Visitors to MCRB typically dress 0.5 clo (trouser or knee-length skirt and short-sleeve shirt) and maintain a metabolic rate of about 1.5 met (walking on a flat surface at less than 0.5 m/s or standing). With mean radiant and air temperatures of 25°C and relative humidity at 60%, PMV values are 0.6 with no air movement and 0.1 with an air velocity of 0.5 m/s. Although a threshold air velocity for collection care has not been well established, lower values provide less risk to collections. Therefore, higher air movement needs to be provided only in areas adjacent to visitors while collections remain shielded from the movements.

Finally, the building is frequently visited by school children as an important field study of Brazilian history; therefore, adequate amounts of fresh air must be provided in the library for their safety and comfort.

The project consisted of four parts: assessments, strategy development, implementation, monitoring, and improvements. For the first step, condition assessments were conducted in order to document conditions of the building envelope, historic interior, furniture, and books that were in cabinets, as well as the climates in the library and the outside. Based on results of the assessments, climate improvement strategies were developed. These included repairs of the building envelope, cleaning of the building interior and collections, installation of various climate control equipment, and changes to operational procedures of the museum including visitor pathways. Some necessary modifications to the strategies were allowed during the implementation in order to correct oversights during the planning stages. Following the implementation, the building and its environment were monitored for a period of time to verify the improvement as well as to identify needs for future modifications. The last process should be periodically repeated to achieve and maintain the best possible environment in the library as an important procedure of the environmental management strategy.

CONDITION ASSESSMENTS

The assessment of the building envelope, conducted by the architect of the FCRB (one of the authors), revealed that many doors and windows had poor closure conditions which allowed the infiltration of large amounts of outside air at all times. They had either misaligned or decayed components that needed to be repaired or replaced. The architect also examined the building's original features for thermal comfort as well as protection against high humidity. Cellar openings, originally designed to naturally ventilate moisture from the space, were closed off with glass windows installed in the 1980s to utilize the space for storage and temporary exhibitions. The building had an original warm-air venting feature consisting of open spaces at the perimeters of the ceilings, the large attic, and loosely stacked roof tiles. However, the recent installation of a Tyvek membrane under the roof tiles (to prevent the infiltration of rainwater and dust in the event of a tile failure) blocked the hot air removal from the attic.

The environmental assessment documented the hot attic and the humid cellar. These spaces are likely impacting the climate in the library. (Fig. 2) The open-window ventilation practice resulted in large fluctuations of both air temperature (22-34°C) and relative humidity (40-90%), as well as high levels of air pollution and particulate matters in the building. However, the climate within the book cabinets was not humid (less than 70% RH) and remained very stable. Furthermore, we found the least amount of oxidizing air pollutants in the cabinets (Fig. 6), indicating that the cabinets were providing a protective microenvironment, shielding books from the poorly maintained library environment.

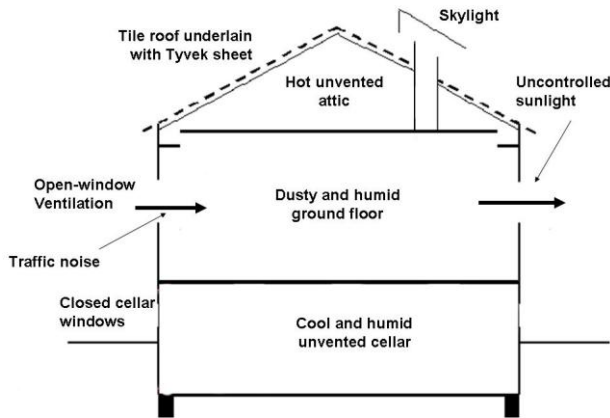


Figure 2: Climate conditions in the MCRB identified through initial assessments

FCRB's conservators also conducted collection assessments of both furniture and books in the library. The furniture assessment showed that it was generally in good condition. However, many of the book cabinets' doors and covers were either misaligned or warped,

resulting in poor closure. Numerous books were affected by the acidification process of typical 19th century papers; some had mechanical damages due to mishandling, past fungal and insect attacks; and many were affected by the accumulation of dust due to a combination of a dusty environment and lack of cleaning.

CONSERVATION STRATEGIES

Recommendations from the above assessments were combined to produce conservation strategies for the library. First, the building envelope needed to be repaired to reduce infiltration, and the original climate control features of the building should be reinstated as much as possible. Climate improvements in the cellar and attic were considered to be especially important. The windows and doors of the library should be kept closed at all times to eliminate infiltration of dusty, polluted and unstable outside air. Books should be cleaned and then returned to the bookcases whose doors had been repaired to close properly. The books would thus be protected from both fluctuations of relative humidity and impacts of air pollution and dusts in the microenvironment of the bookcases.

A climate control system was to be installed in the library cellar to provide filtered clean fresh air and/or conditioned air at 55-65% RH and 22-28° C to the library rooms using ventilation and dehumidification. The supply air, warmer than that of typical air-condition systems, was selected to avoid condensation on supply air ducts and areas surrounding diffuser grills. An exhaust ventilator was to be installed in the attic to reduce heat accumulation. The cellar was to be mechanically ventilated by refitting windows with particle filters to maintain a clean and dry cellar space. As the installation of the climate control system was to be taken place in the cellar and in the attic, it would be hidden from visitors' view and fully reversible.

Climate data in Rio de Janeiro from 2001 to 2005 collected by an independent weather station [5] showed that the ventilation mode is viable only 10% of the time if we require conditions of less than 28°C and less than 70% RH. The window for ventilation expands to only 12%, 14%, 15%, and 16%, even if we raise the temperature threshold to 29°C, 30°C, 31°C, and 32°C, respectively. Therefore, we determined that the system would operate mainly in the dehumidification mode.

Adequate amounts of fresh air must be provided for the safety and comfort of both occupants and visitors. From their operational experience, the FCRB staff determined the maximum number of visitors in the library to be 50 based upon the current arrangement of furniture and visitor pathways. The American Society of Heating, Refrigeration, and Air-Conditioning Engineers

(ASHRAE) recommends fresh air to be provided at the rate of eight litres per second per person. [6] By estimating that the library has an infiltration of outside air at a rate of 1-1.5 air changes per hour (ACHs), we determined that the climate system needs an additional 2 ACHs of fresh air during visiting hours (8 am – 6 pm) in order to limit the carbon dioxide concentration to less than 1000 ppm.

DESCRIPTION OF THE CLIMATE CONTROL SYSTEM

A supply and exhaust ventilator system with a split air-conditioning unit and a programmable control unit with two temperature and relative humidity sensors, one in the library and the other outside of the building, are the major components of the climate control system for the library of MCRB. The split unit is designed to always operate in conjunction with the re-heat coil located immediately downstream of the unit to work as an inline dehumidifier. Condensation from the dehumidifier is drained to the outside drain system via a sump pump. With the exception of the attic exhaust ventilator, all other components are installed in the cellar of the library. These pieces of equipment are connected to each other via a series of metal ducts in the cellar as well as in the attic. Both the outside air and recirculated air passes through G3 filters located at the supply and return ends of the dehumidifier, before being gently released into the library through 30 diffuser grills distributed throughout the library floor along visitor paths. (Fig. 3) Spiral type diffusers are used to allow a large airflow with a limited vertical air velocity.

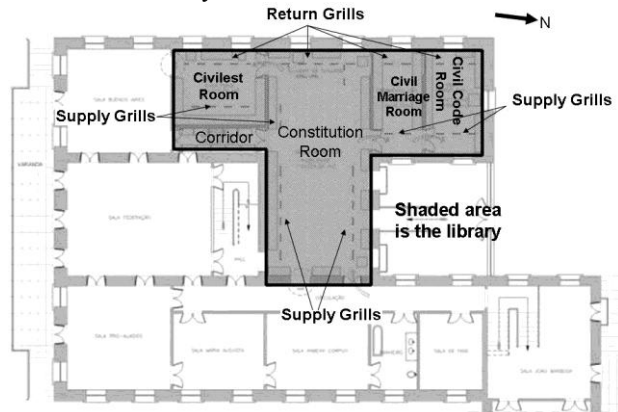


Figure 3: Floor plan for the 1st floor of MCRB showing the location of the library in shaded area and locations of floor diffusers along visitor pathways.

The returning air is taken into duct openings located on the west side of the library floor and ducted to the inlet of the dehumidifier unit. The exhausting air is taken from original ventilation openings at the perimeters of wooden ceilings in the Civil Marriage, Civilist and Civil Code Rooms, as well as the Corridor. (The Constitution Room has a plaster ceiling and therefore does not have ventilation openings at its ceiling.) A large sealed

chamber was created in the attic space above the library rooms. The exhaust ventilator extracts the air from the chamber via a duct and transfers it to the outside through an existing skylight shaft near the library.

A programmable logic control (PLC) unit with a built-in clock, also located in the library’s cellar, controls the ventilation and dehumidification equipment. The PLC is programmed to perform the operational sequences described in the following section by controlling the equipment based on climate conditions reported by two air temperature and relative humidity sensors, located outside the building and in the library.

Modes of Operation:

Five modes of operation: 1) ventilation; 2) dehumidification; 3) hybrid; 4) cooling; and 5) hibernation were created for the climate control system for the library.

Ventilation: The dehumidifier is turned off (but fans are on), the fresh air damper is opened, and the exhaust ventilator is also turned on. 2 ACHs (1260 m³/h) of fresh air is mixed with 8 ACHs (5040 m³/h) of re-circulated air, and then supplied to the library rooms. 2 ACHs of air are exhausted from the attic. This is an energy saving mode.

Dehumidification: The dehumidifier and fans are turned on, but the fresh air damper is closed and the exhaust ventilator is turned off. (Fig. 4) The system operates only to recycle the library air through the dehumidifier at the rate of 10 ACHs (6300 m³/h). This is also an energy conservation mode in which no outside air is treated.

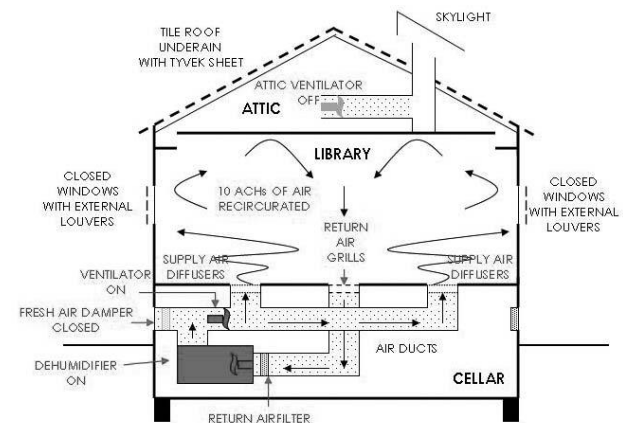


Figure 4: Schematics of dehumidification mode

Hybrid: This mode combines the ventilation and dehumidification modes. 2 ACHs(1260 m³/h) of the fresh air is mixed with 8 ACHs (5040 m³/h) of the recirculated and conditioned air, and then supplied to the library rooms. And 2 ACHs of the library air are exhausted to the outside through the attic. (Fig. 5)

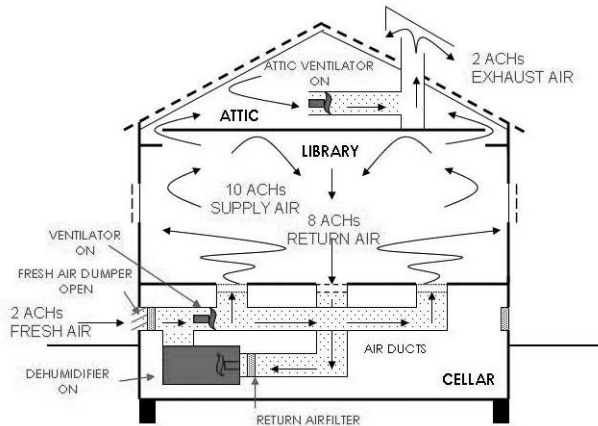


Figure 5: Schematics of the hybrid (dehumidification + ventilation) mode

Cooling: The compressor and air-handler are turned on but re-heat coil is turned off. (The dehumidifier is used as a cooler only in this mode.) The system operates as an air conditioner to provide thermal comfort for visitors.

Hibernation: All equipment is turned off except the sensors and the PLC, once the target condition is achieved (less than 28° C and less than 65% RH). This is an energy saving mode. The PLC activates the equipment when either the air temperature exceeds 28° C or the relative humidity exceeds 65% in the library.

Operational Conditions:

There are three types of operational conditions that determine the mode of operation; the museum’s operating hours, relative humidity, and temperature. The following is a summary of the operational conditions and corresponding operational modes of the system.

Operational Hour: During the museum’s hours of operation, the climate system will operate in either ventilation or hybrid mode. In both modes, fresh air is guaranteed in the library to provide visitor safety and comfort. The system can select the dehumidification mode, however, once visiting hours have ended. The library air is completely re-circulated through the dehumidifier until the relative humidity in the library is reduced to 65%.

Relative Humidity: The control system selects the ventilation mode when relative humidity in the library is higher than 65%, and outside relative humidity is lower than 65% at less than 28°C. If outside relative humidity is above 65%, the dehumidification or hybrid mode is selected depending on the hour of the day.

Temperature: Temperature was added to the system’s operational sequence primarily to provide visitors’ thermal comfort by limiting the library temperature to less than 28°C. Therefore, it is applicable only during the

museum’s hours of operation (8 am – 6 pm). When the temperature in the library is higher than 28°C, the climate system will operate in the cooling mode.

MONITORING AND IMPROVEMENTS

After the installation and initial adjustment period of the climate control system, it has produced and maintained 25 ± 3°C at 60 ± 5% RH in the library when the outside condition varied from 35% to 100% RH at 20°C to 38°C. It showed the system’s capacity to produce and maintain the targeted climate condition in the library during a typical summer.

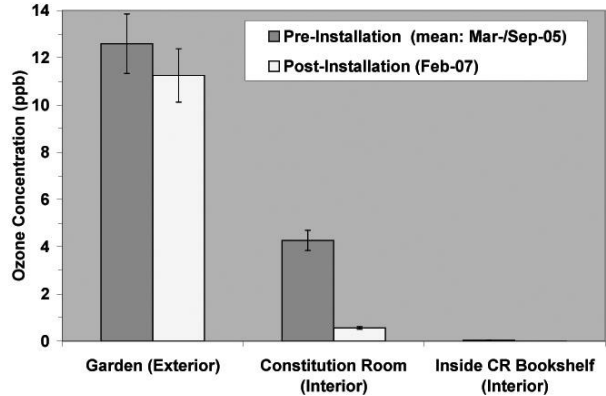


Figure 6: Comparison of ozone concentrations before and after the installation of the climate control system

A comparison of air pollution and particulate data collected in the Constitution Room during pre- and post-climate control system installation periods indicated a reduction in concentration for a number of variables examined. Among the pollutants, the highest decrease was observed in ozone, which displayed an 85% reduction in levels relative to values from pre-installation conditions. (Fig. 6) Post-installation nitrogen dioxide concentrations were also decreased by 30% over pre-installation values. However, results of nitric oxide concentrations were inconclusive. Finally, sulphur dioxide levels were negligible both pre- and post-installation.

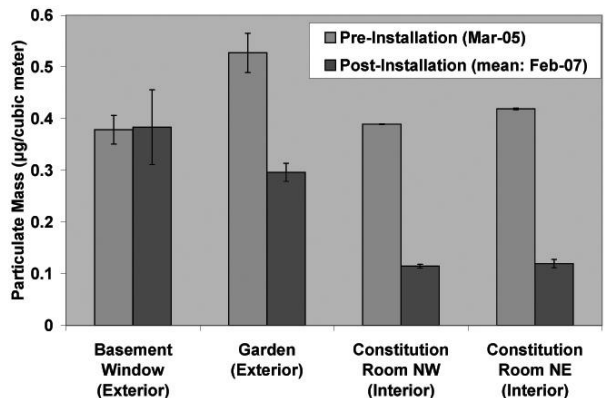


Figure 7: Comparison of 1-5 micron particulate matter before and after the installation of the climate control system

Two airborne particulate size fractions, 1 to 5 micron and 0.3 to 1 micron, were examined. The larger particles exhibited a 75% to 85% decrease in post-installation Constitution Room concentrations. (Fig. 7) Though the smaller size particles also showed lower post-installation values compared to pre-installation values, the extent of decrease in the Constitution Room was not conclusive.

Air velocities at 50 cm above floor supply grills ranged from 0 to 0.3 m/s with the majority less than 0.1 m/s. We identified several leaks of the supply air at diffuser boxes mounted in new floorboards that were replaced for this project. (Removed original floor boards were stored away with location identifications.) Similar air leaks were identified at return grills resulting in an ingestion of unconditioned basement air into the return duct. Several attempts were made to repair the leaks; however, the thickness difference between the original and replacement floorboards as well as locations of structural members made the repair difficult. In spite of significantly lower air movements at visitor pathways than originally designed for, the majority of visitors indicated the library environment as comfortable. Visitors' comments indicated that the air is noticeably fresher and drier, and the temperature seems cooler, possibly resulting from the filtered and drier air. Closed doors and windows also reduced noise and harsh sunlight, and may have contributed to visitors' comfort.

Over the course of operation the climate in the library drifted away from the designed condition. We identified the problem to be the complexity of the PLC's program resulting from too many operational modes and conditions in its logic. It became difficult to diagnose problems due to its complicated program logic. Furthermore, although the climate control system consists of standard off-the-shelf equipment, maintenance contractors were unwilling to accept a maintenance contract due to uncertainties associated with unfamiliar equipment design.

CONCLUSIONS

A ventilation/dehumidification-based climate control strategy was successfully implemented in a historic house museum in a hot and humid climate. It established and maintained a safe collection environment for both the historic building and its collection, which is a stable relative humidity environment at less than 65% RH while allowing temperature variations between 22°C and 28°C and avoiding condensation or high humidity conditions in or on the building envelope. It has also shown the ability to provide for human comfort. Although the designed level of air movement was not achieved along visitor pathways due to difficulties encountered during the installation of floor diffusers, visitors have expressed comfort in the library due to lower humidity, a clean-air

sensation, the elimination of direct sunlight, and lower noise levels.

The success of the project was attributed to a well-structured project design, execution, and evaluation. Assessments of the building, the collection, and the environment provided essential information for developing an improvement strategy, an integrated approach that combined the building, collection, and the climate control equipment as one environmental system. Monitoring that followed the implementation produced useful information for equipment adjustments and future improvements.

This climate improvement project, which successfully produced an environment for both the collection preservation and human comfort in a historic house museum, paved the way to a wide application of this low-cost, relatively simple climate improvement strategy in cultural institutions in hot and humid climates.

Acknowledgements. This project was funded by Fundação Vitae (São Paulo, Brazil). The authors wish to thank Fundação Vitae and Mrs. Gina Machado, then a project manager, Area of Culture, Fundação Vitae, for financial and logistic support as well as encouragement throughout the project. The authors also acknowledge technical contributions of Ms. Carla Maria Coelho, then an architectural intern at FCRB, during the project.

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