Investigations of Climate Control Alternatives for Cultural Institutions in Hot and Humid Climates.

By Shin Maekawa

Introduction

In 1997 the Getty Conservation Institute (GCI) initiated a project to develop strategies for preserving collections in hot and humid climates. The project began with an experts meeting in 1998 hosted by the GCI to identify issues of preventive conservation for collections in tropical and subtropical regions. The experts agreed that biodeterioration of collections is a major concern for cultural institutions in regions where favorable conditions for insects, fungi, and bacteria are found. In fact, the threat posed by biological and microbiological attacks often supersedes the potential for chemical aging or mechanical damage. From discussions at the meeting, it became evident that three topics merited further study:

- Assessment methodologies for threats to collections and the buildings housing them
- The control of pollutants and daylight
- Economical and sustainable climate improvement strategies (i.e., effective alternatives to air-conditioning systems), primarily to control biodeterioration

Following this meeting, the GCI initiated the work in the first and third areas. During the latter part of the 1990s, the GCI developed a set of guidelines to evaluate the environment of museum collections and their buildings (www.getty.edu/conservation). For the second area, the GCI undertook several related studies. The first study evaluated the efficacy of several practical climate control strategies proposed for historic houses which were considered to have great applicability to hot and humid regions. A second study focused on ventilation methodologies to control microbial activities in cultural institutions in the same climate zones. Then the GCI applied the results of the above studies to full-scale test installations of alternative climate control systems in historic buildings at two hot and humid sites. These successful tests were followed by applications in which local engineers, architects, and installation companies were contracted to install alternative climate control systems in cultural institutions based on the author's conceptual design; three case studies were documented as the final phase of the project. These studies raised several important issues that need to be addressed for wider application of project results.

Efficacy Evaluation of Practical Environmental Improvements at Shelburne Museum

In 1993 the Shelburne Museum in Shelburne, Vermont, and the GCI collaborated to evaluate the efficacy of environmental improvements that the museum was going to perform on each of the thirty-three buildings at the site (Kerschner 1992). The project presented a unique opportunity to evaluate the effectiveness of these practical climate control strategies by use of environmental monitoring tools.

The climate of Shelburne is typical of New England. The daily average temperature ranges from –27°C in winter to 28°C in summer, with a typical daily variation of 15°C to 20°C. In summer the temperature rarely goes above 30°C. Precipitation is about 850 mm and is distributed throughout the year in the form of snow and icy rain in the winter and rain in other seasons. The heaviest rain occurs in summer. Relative humidity (RH) ranges from 90% in the morning to 60% in the early afternoon.

A series of environmental monitoring tasks was performed in three of the Shelburne Museum's buildings: Prentis House (an eighteenth-century two-story timber residence), the Horseshoe Barn (a large, horseshoe-shaped two-story barn), and the Stagecoach Inn (an eighteenth-century Georgian-style town hall building). These buildings were planned with different levels of climate improvement strategies. The Prentis House system consisted of humidistat- and thermostat-controlled low-level wintertime heating and summertime ventilation. In the Horseshoe Barn, a ventilation treatment of the entire structure controlled by both a thermostat and a humidistat was applied. And in the Stagecoach Inn, the design utilized centrally controlled air-conditioning with humidification based on an adjustable set point, depending on the season, to reduce the hygrometric stress on both the building and the objects.

Climatic data were collected over a five-year period that included years before and after the implementation of the three systems. Temperature and RH both inside and outside the targeted buildings were statistically analyzed for the evaluation of environmental improvements. The environments of Prentis House and the Stagecoach Inn showed significant improvements from prior conditions, and their respective climate systems produced favorable climate conditions. However, climate improvements were not measurable in the Horseshoe Barn, probably because of the structure's large natural infiltration rate (measured in air changes per hour) of 7 ACH. These results indicated that the tested climate improvement approaches were safe and effective for historic buildings and collections. However, a building has to have a limited rate of air infiltration for any climate system to be effective (Maekawa 1999).

Establishment of Ventilation Experiments for Controlling Microbial Activities

The dual focus of this first component was to identify microbial species present in historic buildings and to investigate the use of ventilation to control or arrest microbial activity in historic buildings in hot and humid regions. With support from the GCI, the Center for Biological Investigation in Madrid, Spain, investigated fungal and bacterial species commonly found in Spanish cultural institutions, as well as the environmental conditions necessary for their activities.

In the second year of this research, a series of laboratory experiments was conducted in a 500 L environmental chamber to identify ventilation strategies to arrest fungal and bacterial growth on paper surfaces and in the environment (Valentín et al. 1998; 2001). A set of similar experiments was performed during the third year to simulate more realistic field conditions. For larger-scale experiments, hot and humid environments were produced in a small basement room of the National Historic Archive of Spain in Madrid, an early twentieth-century, non-air-conditioned historic building (Valentín et al. 2002).

The use of even a low ventilation rate in the range of 0.48–1.2 ACH was found to be effective in decreasing environmental contamination in a test chamber, as well as on paper samples at 85% RH and 24°C. The germination of fungal spores was prevented. However, it is necessary to maintain air movement even in those areas where ventilating air may not normally reach. Lower temperatures than that of the environment were detected on surfaces of contaminated papers, but effective ventilation elevated the temperature to that of the environment.

Full-Scale Installation Experiments in Two Historic Buildings

In late 1998 two historic buildings in hot and humid regions were selected for full-scale experiments for alternative climate control strategies based on humidistat-controlled mechanical ventilation and space heating. One was the Historic Archive in a municipality building of La Laguna on Tenerife Island, Spain; the other was Hollybourne Cottage in the Jekyll Island Historic District on Jekyll Island, Georgia, USA. Both structures are located in subtropical climates (Maekawa and Toledo 2002).

Historic Archive of La Laguna's City Hall

San Cristóbal de La Laguna (505 m above sea level) is located in the north side of Tenerife Island, Spain. The city is known to have a mild but humid climate throughout the year that is classified as subtropical. Light westerly sea breezes are present on the island throughout the year. Significantly higher monthly rainfalls have been recorded from November through March, although rain can fall year-round, with an annual average accumulation of 600 mm. August is the hottest month, with an average temperature of 20.3°C and average RH of 73%. January is the coldest month, with an average temperature of 13.6°C and average RH of 79%. The annual mean temperature and RH values in the thirty-year record were 16°C and 75% RH.

The Historic Archive is housed in a late-nineteenth-century building that originally belonged to an order of Dominican nuns. It is a massive two-story building made of local volcanic tuff with an above-grade basement that surrounds a patio. When it was refurbished in 1985 to accommodate several municipal offices, the majority of exterior doors and windows were permanently closed to provide security and protection against outside forces. These modifications, however, altered the original ventilation features of the building, creating many pockets of stale air, which in turn forced the staff to use portable dehumidifiers to control high humidity levels in an effort to arrest microbial activities. However, during long weekends, the dehumidifiers often stopped after collecting their maximum amounts of water in their reservoirs, resulting in humid environments in the archives until the dehumidifiers were manually reactivated by staff members once the workweek had started.

Humidistatically controlled ventilators that produced 6 ACH and a convective heater-based climate control system were installed in two small rooms containing the Historic Archive in 1999 (fig. 1). After nearly one year of operation, we confirmed that the system not only successfully eliminated events of above 70% RH but also stabilized the environment (Maekawa and Toledo 2001b, 2002, 2003). The annual temperature variation was significantly reduced, although daily variations increased. The installation of a particulate filter at the supply ventilator contributed to drastically reducing the dust level. The room's moisture content was reduced to less than that of the outside. Although microbial activities were reduced in the environment, microbial counts remained unchanged on documents. The system was simple to install and inexpensive to operate. However, comments from staff members of the archive indicated that the environment in these rooms was sometime uncomfortable: too cold, too drafty, or too hot.

Hollybourne Cottage, Jekyll Island

Jekyll Island is located on the Atlantic coast of Georgia in a warm, humid, cooling required climate region, as defined by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE 2005, Chapter 28). The sandy island is slightly above sea level and mostly flat. June, July, and August are the hottest months, with temperatures averaging near 26°C. December, January, and February are the coolest months, with temperatures near 10°C. The average RH is 75%, ranging from a measurement in the upper 90s in the early morning hours to about 55% in the afternoon. Most of the rainfall occurs during the summer months, and the annual average precipitation is 1,271 mm.

Constructed in 1890, Hollybourne Cottage is in a progressively deteriorating condition; it is the only nonrenovated building remaining in the Jekyll Island Historic District. The T-shaped building is a two-and-one-half story residence (approximately 300 m^2 per floor with 2.5 m ceilings) with a full basement. Exterior walls are composed of tabby concrete, and the foundation system is of double brick walls that carry much of the structural load. Interior finishes are plaster on wood laths for walls and ceilings. Floors are wood planks over a wooden subfloor. The majority of wood deterioration is found in the basement and on the ground floor.

Following a period of climate monitoring of the site and inside the structure, an experimental climate control system (consisting of sets of supply and exhaust fans, convection heaters, sensors measuring RH and temperature, and a programmable controller) was installed in the basement and attic of the cottage in 2000. The system was designed to maintain a conservation environment—that is, to sustain RH at lower than 70% while allowing the temperature to vary. By directly improving the climates of the attic and basement, which were the two worst climates in the house, we would indirectly achieve the environment on exhibition/storage floors, which are the first and second floors. For more than a year, the system successfully maintained a conservation environment, and both equipment and energy costs were kept to less than 20% of the costs of typical air-conditioning-based systems (Maekawa and Toledo 2001a).

During the next five years, we examined various configurations of climate control schemes, including ways to provide comfort for visitors in the exhibition space (Maekawa, Beltran, and Toledo 2007). The following modifications were tested (table 1):

- lowering of RH set points;
- relocating ventilators in the basement and attic;
- ventilating the first and second floors;
- dividing the building into two or three zones;
- using dehumidifiers instead of convective heaters;
- opening floorboards of the ground floor for increased cross-floor airflow;
- activating ventilators based on absolute humidity rather than on RH comparison.

	Phase					
	1	**2**	**3**	**4**	**5**	**6**
Location	Jun 00 to Feb 01	Feb 01 to Aug 01	Aug 01 to Jun 02	Jun 02 to Jul 03	Aug 03 to Apr 04	Apr 04 to Jun 06
Basement	**Heating & ventilation** (based on basement RH)	**Heating & ventilation** (based on basement RH, connected to 1st floor)	**Heating** (based on basement RH, segregation from 1st floor beginning with phase 3)	**Dehumidification** (based on basement RH)	**Dehumidification & ventilation** (based on basement RH)	**Dehumidification & ventilation** (same as phase 5, with addition of basement dew point temp. control)
1st floor		**Ventilation** (based on basement RH, connected to basement)	**Ventilation** (based on 1st-floor RH, not connected to basement, 2nd floor, or attic fans)	**Ventilation** (same as phase 3)	**Ventilation** (based on 1st-floor RH and attic roof temp., connected to 2nd floor and attic fans)	**Ventilation** (same as phase 5, with addition of 1st-floor dew point temp. control)
2nd floor		**Ventilation** (based on attic roof temp., connected to attic)	**Ventilation** (based on 2nd-floor RH, no roof temp. control)	**Ventilation** (same as phase 3)	**Ventilation** (based on 1st-floor RH and attic roof temp.)	**Ventilation** (same as phase 5, with addition of 1st-floor dew point temp. control)
Attic	**Ventilation** (based on attic RH, air temp., and roof temp.)	**Heating & ventilation** (based on attic roof temp.)	**Heating & ventilation** (based on 2nd-floor RH, no roof temp. control)	**Heating & ventilation** (same as phase 3)	**Heating & ventilation** (based on 1st-floor RH and attic roof temp.)	**Heating & ventilation** (same as phase 5, with addition of 1st-floor dew point temp. control)

Table 1

Detailed test configurations of the experimental alternative climate control system in Hollybourne Cottage, Jekyll Island Historic District, Jekyll Island, Georgia, USA. The different colors indicate different climate zones.

The climatic conditions of each space were adequately addressed during all phases of the study. Continued segregation and control of the basement space, the dominant site for moisture source and a heat sink during summer months, limited the transfer of humid conditions to higher floors. Because the basement lacked significant visitation or work activity, its climate control did not require ventilation and could rely solely on a heating or dehumidification mode. The choice between heating and dehumidification can be made by comparing the reduced energy costs of dehumidification to the lower capital and maintenance costs and quiet operation of heating.

The use of attic ventilation addressed peak summer temperatures in the space, while heating was used to limit the elevation of RH during the cooler winter months. Though limited in its capacity to reduce mean temperature, the use of ventilation was shown to lower maximum attic temperatures. The use of thermal insulation may minimize or even eliminate the need for attic heating.

From a preservation standpoint, the use of ventilation on main floors should be avoided if possible, as intermediate spaces will be effectively buffered by the controlled environments of floors above and below. However, intermittent visitation provokes ventilation needs as a means of improving visitor comfort. Manually activating ventilators during periods of active use, even if the outside RH were higher than 75%, followed by overnight dehumidification, would also maximize the window of opportunity for the ventilation mode.

Compared to the typical energy budget for an HVAC system, the alternative climate control strategies applied at Hollybourne Cottage offered a significant savings in operational and maintenance costs. The operational costs represented a reduction of 27% to 73%, relative to that of a typical air-conditioning system. Furthermore, the capital cost was only 20% of a typical climate control HVAC system.

Three Case Studies of Application

As a result of the successful experimental trials discussed above, a number of cultural institutions expressed interest in applying alternative climate control strategies in their facilities located in hot and humid regions. These projects were supported through the use of local resources, including funding for labor and equipment and the hiring of local engineers, architects, and contractors. The GCI provided concept designs, technical supervision during engineering and installation of these systems, and performance monitoring and suggestions for improvement. The followings are three case studies carried out under the above arrangements.

Museum Storage in Valle Guerra, Tenerife, Spain

A collection storage facility (Valle Guerra, Tenerife) for the Autonomous Entity of Museums and Centers of the Island Government of Tenerife occupies the second floor of a contemporary four-story concrete building located on the northeast hillside of the island. Valle Guerra is a rural village on the north side of Tenerife; its elevation is 195 m, and it is 4 km off the coast and approximately 10 km northwest of La Laguna, the site of the previous experiment discussed above. The village is protected from easterly winds by hills at its southwest that are 600 m high.

The storage space, 437 m^2 with a 3 m ceiling, is divided into five rooms, with windows located only on the northwest and northeast walls (fig. 2). The northeast side of the room faces the Atlantic Ocean, while a narrow paved road brackets the northwest side of the structure. The other two sides are subgrade, as the building sits in a slope. The stored collection consists of ceramic potteries, basketries, wooden and metal tools, textiles, and modern machinery.

Prior to this project, the environment of the storage facility was not controlled. Rooms C, D, and E were identified as colder and more humid because of their exposure to the cold and humid northwest wind. Major attempts were made to reduce the infiltration of outside air by sealing the building envelope. All external windows were either fitted with ventilators or sealed and insulated. Internal windows and doors, except one to Room C, were removed in attempt to produce good air mixing.

The installed climate control system in the storage facility consisted of three sets of supply and exhaust ventilators, five convective heaters, and three humidistats (fig. 3). Since there was no possibility of installing windows on either the southwest or the southeast wall to achieve cross-ventilation, supply air was taken from the northwest wall and transferred via ducts to the southeast ends of the room, where it was released into the space. The exhaust ventilators were mounted on the existing windows of the northeast wall. The heaters were initially located at corners of the storage; however, two of them were later moved to Rooms D and E (Maekawa and Morales 2006).

The climate control system at the Valle Guerra storage facility has been in operation since August 2002. Although the targeted RH has been maintained since installation (figs. 4 and 5), a large climatic variation still existed in the rooms, similar to conditions before installation. Several minor modifications, such as the relocation of an RH sensor and heaters to Rooms D and E, have since been performed. During the period from January 2004 to September 2005, the RH levels in the four rooms have been maintained at or below 65%, with daily variation of less than 10%, while the temperature has varied between 18°C and 30°C throughout the year. Both the capital and operational costs have been estimated to be less than 20% of a typical air-conditioning-based system.

Unwillingness of a contracted mechanical engineer to follow the author's concept resulted in his dismissal about three-quarters of the way through the project. This situation resulted in significant schedule delays, technical compromises, and increased cost. Staff members of the museum mentioned sometimes uncomfortable temperatures (too hot or too drafty) and complained of working in a sealed space with artificial light for extended periods of time. High noise levels from the ventilator may also be a negative contributing factor.

Ethnographic Storage in Belém, Brazil

The Amazonian ethnographic collection of Museu Pararense Emílio Goeldi (MPEG), Belém, Brazil, consists of about fifteen thousand objects from different ethnic groups: objects used in agriculture, fishing and hunting, food processing, ceremonies, and celebrations. The objects are mostly basketry, instruments, and ornaments; and they are generally made from plant fibers, woods, seeds, and bird feathers. The climate in Belém is classified as tropical; it has an annual average temperature of 26ºC and RH of 86.5%. The maximum temperature never exceeds 32.5°C, and the minimum of 22.5°C is often recorded in the rainy season. It rains daily in Belém. The annual rain accumulation averages 2,890 mm.

The majority of MPEG's storage environments are maintained by dual sets of several room air-conditioning units, which are utilized in day and night shifts for extended maintenance-free operation of continuous climate control. However, these units are designed to produce low temperatures for human comfort and not for maintaining a stable preservation environment for collections. As a result, both the temperature and the RH vary significantly, and there is a major threat of condensation on both collections and buildings (Hussak van Velthem et al. 2004).

High energy consumption of air-conditioning systems is another problem. Including the daytime use of room air-conditioning units in individual office spaces, the museum spends about 70% of its total operating budget on electricity. With the nationwide energy crisis in 2001, the Brazilian government mandated its facilities to reduce energy consumption by 30% by 2007. In addition, frequent and extended power outages, very common in the region, are another reason for fungal and mold outbreaks. The museum was therefore searching for an innovative climate control approach that would be low in cost for both installation and operation, technologically robust, and capable of maintaining a stable conservation environment, even in a period of an extended power outage.

The new ethnographic storage area measures 15 x 18 m (270 m^2), and it has a cement slab floor and a concrete slab ceiling (3 m high). The walls are of fired hollow bricks finished with cement plaster and white water-based paint. The installed climate control system consisted of two large supply ventilators, four smaller exhaust ventilators, six oscillating fans, four portable dehumidifiers, and two humidistats. The supply ventilators were placed outside the building, bringing filtered outside air through two centrally located ducts mounted under the ceiling, and distributing air through five diffusers on each side. The venting air, after flowing through shelves and drawers, was collected near the floor through two ducts with five return openings each, as well as along two walls parallel to the supply air ducts, and was ducted to the exhaust fans located in wall cavities. Four portable dehumidifiers connected to permanent drains were located in four corners of the storage room. Three oscillating fans mounted near the ceiling on sidewalls operated with the dehumidifiers for mixing the room air. Another three oscillating fans, independently operable, were installed on center columns to provide comfort for staff members and researchers. Two humidistats, with one RH sensor inside the storage area and the other outside the building, controlled the operation of ventilators, fans, and dehumidifiers.

The climate in the storage area was monitored for a three-year period after the system's installation. The system has been operating successfully, maintaining the storage at 65%–70% RH and 31°C–33°C (figs. 6 and 7). The dust level in the storage area has remained significantly lower than the level outside, which is also true for offices and the open corridor located in the same building (Maekawa, Toledo, and Arraes 2006).

Through a collection assessment that was conducted one year after the installation of the climate control system, both the curator and the conservator of the collection confirmed that they found no damage to any of the objects in the new storage environment. Meanwhile, staff members have noticed that the collections have obtained increased volume and color saturation, particularly those made of feathers and vegetable fibers. These objects seem to have achieved rehydrated conditions in the new environment, with their moisture content being similar to what it would be in the native environment.

Costs for installation, engineering, equipment, and labor were less than 20% of a typical climate control system that controls both temperature and RH. The ventilators or dehumidifiers have, on the average, operated only about four hours per day, mostly during the daytime. Per unit area, the storage currently expends 20% of the average energy use compared to the rest of the campus. During the two years of continuous operation of the system, the only maintenance needed, other than annual calibration of the humidity sensors and filters replacement, was replacing a failed solenoid switch for powering one of the ventilators. This failed component had minimal impact on the climate of the storage area. Several events of extended power failure, one lasting more than thirty-four hours, were recorded during the operation; however, they had only minor impact on the climate in the storage area, which, for the majority of the period, maintained the designed RH. These events have also proved that the system's operation is robust.

With ASHRAE's design dew point temperature of 29°C at Belém, we expected the temperatures of the storage area to be 30°C–31°C with the utilization of dehumidifiers instead of heaters. However, the maximum temperature was 33°C. The higher temperature may be the result of inefficient dehumidifiers. Although the temperature is as high as that of a sunny afternoon outside, by utilizing installed oscillating fans, staff members have been able to work for extended periods of time in the storage area. A concern over the issue of accelerated chemical aging was raised.

Library of the Casa de Rui Barbosa Museum, Rio de Janeiro, Brazil

Located in the busy Botafogo district of Rio de Janeiro, the house museum of Rui Barbosa was home to one of Brazil's most prominent jurists and intellectuals of the late nineteenth and early twentieth centuries. Casa de Rui Barbosa Museum was opened to the public in 1930 and was thus the first house museum in Brazil. With the bulk of Barbosa's book collection on display in the museum, the five library rooms are also the most visited areas of Casa de Rui Barbosa.

While other case studies of the Alternative Climate Control project have examined applications to storage areas with limited visitation, Casa de Rui Barbosa presented the unique opportunity to address visitor comfort issues along with collection conservation and historic building preservation. Except for localized air-conditioning units positioned in working areas, interior conditions of the museum have remained largely uncontrolled. Open-window ventilation throughout the house has also been reduced as several windows, once open, are now closed to minimize the damaging effects of sunlight and air pollution. An important aspect in the climate improvement strategy was to reinstate the original passive climate features of the building that had been previously obstructed (Maekawa, Carvalho, and Toledo 2006).

Environmental and building assessments carried out prior to installation identified two such passive features, which became integral to the strategy's design. In the library, aside from cross-ventilation through existing large windows, the original airflow path included venting warm air through the ceiling perimeter into the attic, which used to be well-ventilated (therefore, cooler), loosely stacked roof tiles. Similarly, the closure of wall openings in the cellar limited cross-ventilation and moisture dissipation in the space. The design of the climate control strategy included reinstating these original passive features but enhancing them with mechanical ventilation. These enhancements improved the climate not only in the library but in the attic and cellar spaces as well.

An installed climate control system was located in the cellar, away from public view (figs. 8a and 8b). The supply ventilator and dehumidification units are connected to the library space by ductwork to thirty diffuser grills on the library floor; the diffusers allow for large airflow with minimum vertical air velocity. Formerly supplied to the library rooms, conditioned air was either returned to the dehumidifier via floor grills or exhausted to the exterior through the ceiling perimeter and attic space by an extraction fan positioned in the attic and exhausted through the skylight. Ventilation is also supplied to the cellar through the operation of the dehumidifier's heat removal fan, which draws in filtered air through reopened wall openings. In order to maintain RH in the library at less than 65%, a programmable logic control (PLC) unit controls return and exhaust air, as well as ventilation and dehumidification, by monitoring RH and temperature conditions for the exterior and library. With the improved climate in the library, the extensive collection of books is further protected in the original wooden cabinets.

The objective of addressing human comfort, however, introduced additional considerations for the climate control system. Good indoor air quality typically requires 7–8 L/sec/person of fresh air to limit the buildup of carbon dioxide. Though this criterion was satisfied during the ventilation mode, dehumidification (or natural infiltration of the outside air) would be unable to provide enough adequate fresh air to the library for the maximum capacity of fifty visitors. Thus, a hybrid mode was added that triggered dehumidification and ventilation simultaneously during visiting hours. Continuous movement of 10 ACH of air through the climate-controlled space during museum operating hours would also promote cooling of the skin surface, thus enhancing human comfort. Although this hybrid mode was not capable of the level of temperature control provided by a conventional air-conditioning system, the maximum interior temperature target at the library was reduced to 28°C in an effort to improve human comfort while avoiding the possibility of condensation in the building.

Following preliminary testing of the system in October 2006, an initial trial was conducted on a typical spring day to measure its ability to meet interior environmental targets. With exterior conditions of 27°C and 80% RH, the dehumidification mode produced and maintained a stable library environment of 25°C and 60% RH. A shift to the hybrid mode, in which both dehumidification and ventilation are active, maintained an interior condition of

25°C and 62% RH. The climate system has been providing a refreshing environment in the library. The sensation may come from drier air and slightly cooler temperatures. Closed windows and doors also cut down the transmission of outside noise.

The performance of the Casa de Rui Barbosa climate control system will continue to be monitored for the next six months to assess its capability through a range of outside environmental conditions. Of particular importance will be system performance during the summer months, from January to March, when annual maximum dry bulb and dew point temperatures are typically recorded.

Conclusion and Recommendations

All tested climate control systems—alternatives to conventional air-conditioning-based systems—produced preservation environments for both collections and buildings that house them. Both installation and operational costs were significantly lower (one-fifth to one-third lower) than conventional air-conditioning-based systems in museums. However, several issues unique to these installations were raised during the trials:

- Human comfort in storage/archive environment: preservation-focused environments were sometimes too hot or too drafty for staff members to access or work in. Also, closed/sealed rooms were inhospitable.
- High noise from ventilators and dehumidifiers in nonducted installations: a special design is necessary to reduce noise from equipment if the climate system is exposed to a gallery or storage spaces.
- Concern over accelerated chemical aging rates of ethnographic collections due to higher (31°C–33°C) temperatures: chemically sensitive materials, such as papers, films, photographs, and plastics are known to accelerate chemical aging processes in elevated-temperature and elevated-RH conditions. However, concerns were also raised for ethnographic materials, such as straw and feathers.
- A close working relationship with mechanical engineers and architects is needed—mechanical engineers wanted to follow more conventional air-conditioning approaches

rather than alternative approaches. Repeated meetings with the engineer and the project architect were necessary to realize the concept.

- Sustainability: it is necessary to train staff members to monitor the environment. It has been difficult to obtain reasonable rates for service/maintenance agreements from contractors.

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Author Biography

Shin Maekawa has a BS in Engineering Applied Mechanics from the University of California, San Diego, a MS in Mechanical Engineering from the University of California, Los Angeles, and a PhD in Conservation Science from Tokyo National University of Fine Arts and Music. He has been a senior scientist in charge of the Environmental Studies Laboratory of the Getty Conservation Institute since 1989, where he oversees and conducts research on climate control technologies for historic buildings, as well as research on microclimates of cultural objects for conservation. He is a registered professional engineer (mechanical) in California.

Figures

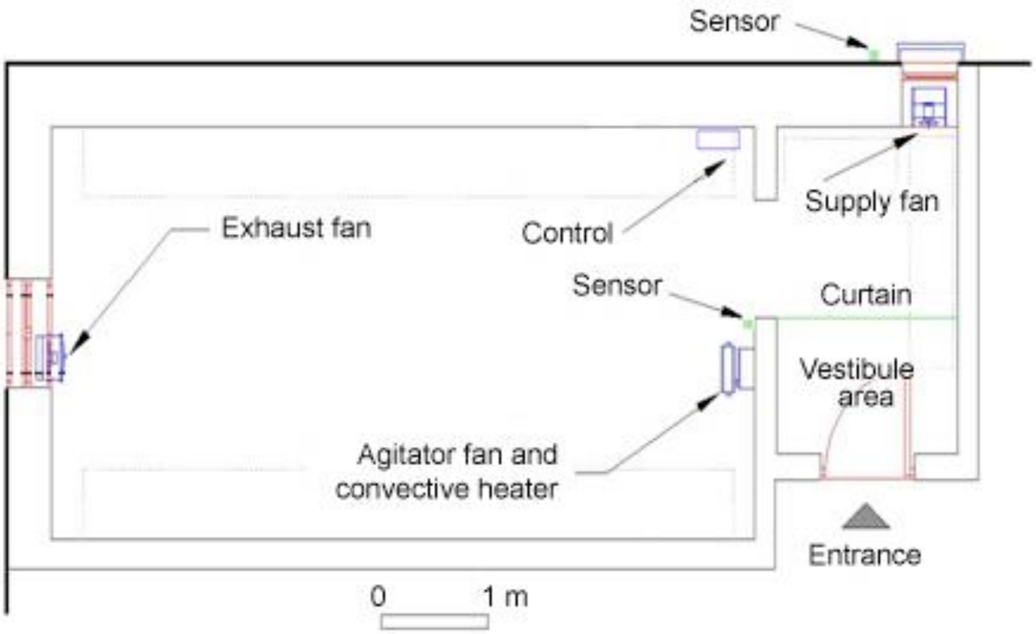


Figure 1

Plan view of the alternative climate control system for the Historic Archive of La Laguna Municipality, Tenerife Island, Spain.

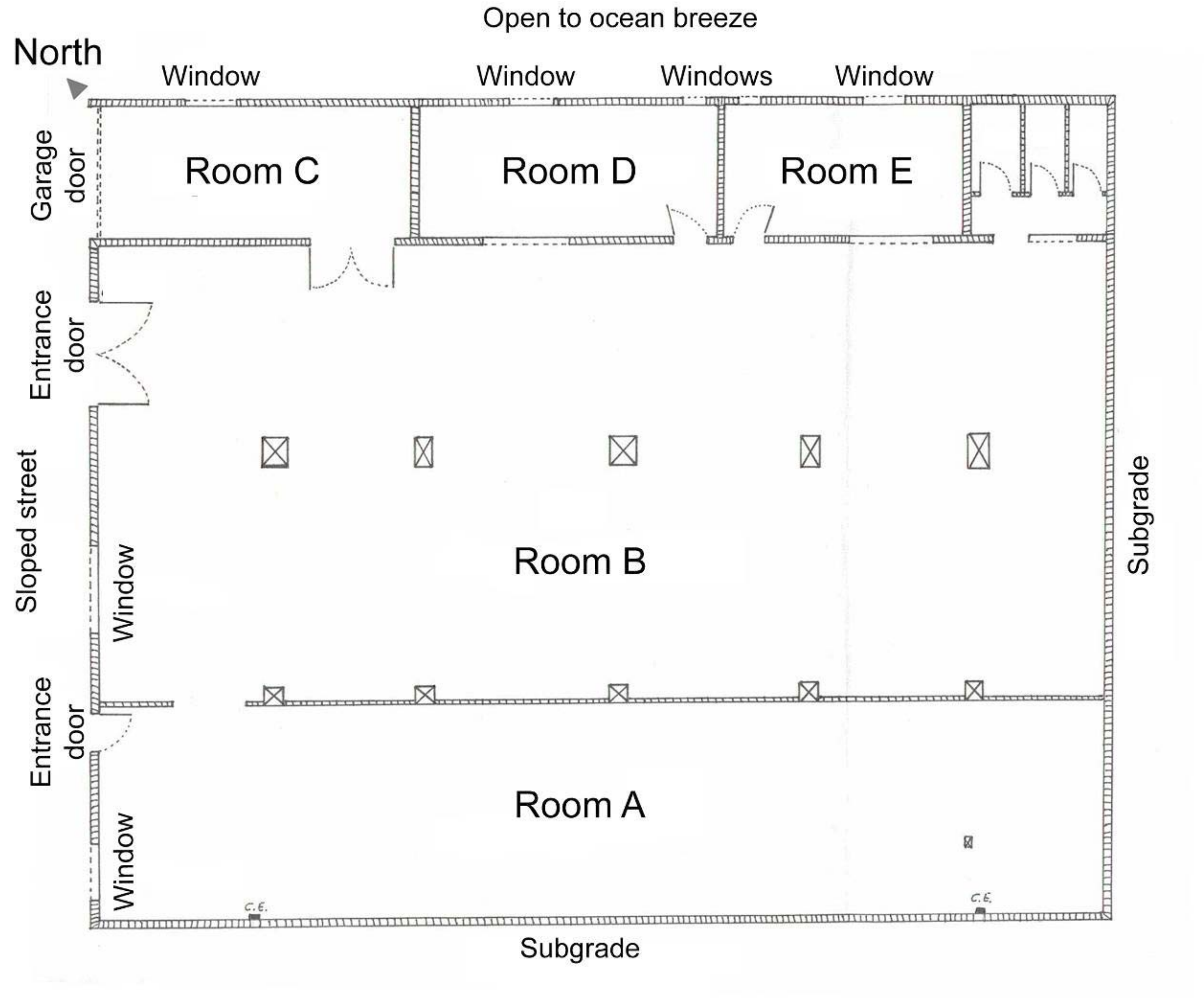


Figure 2

The original distribution of space in the museum storage area at Valle Guerra, Tenerife Island, Spain.

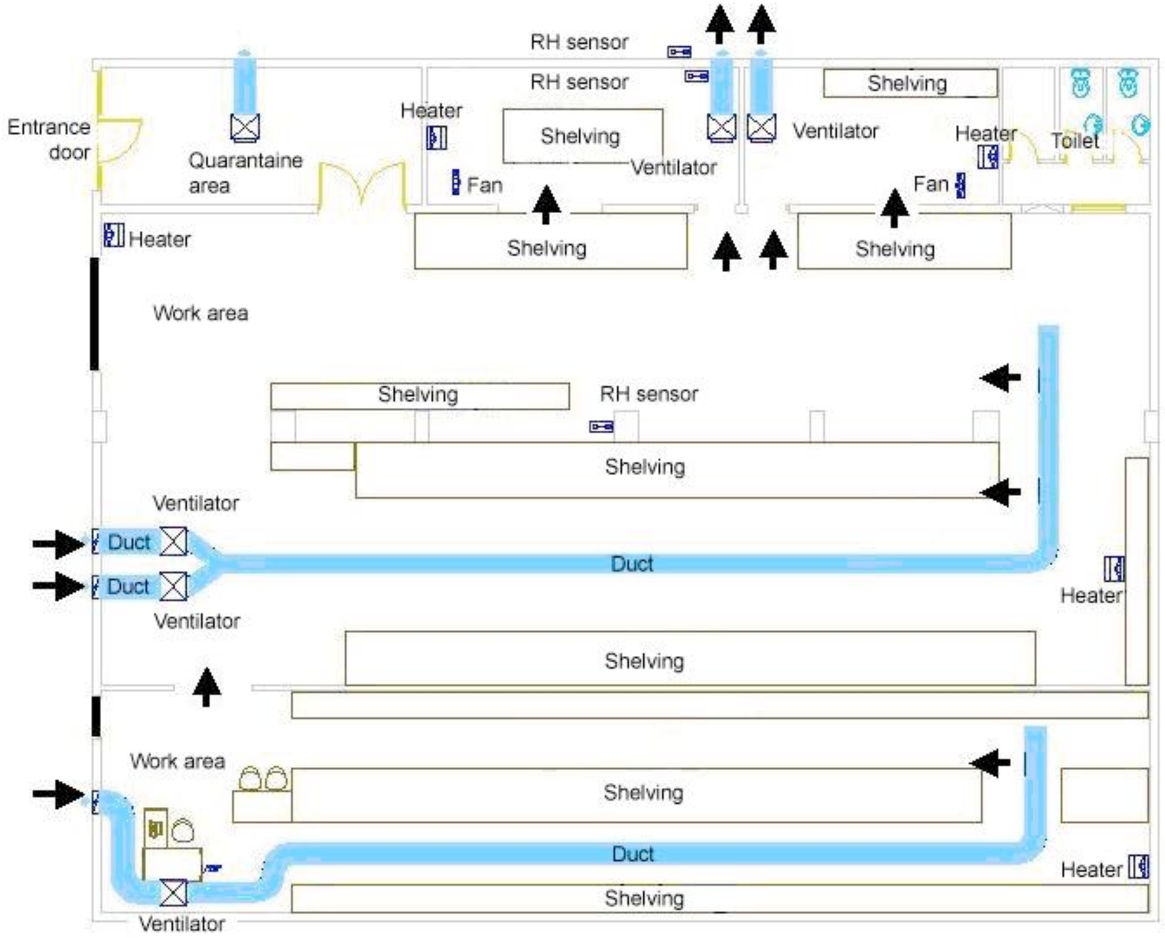


Figure 3

The layout of the alternative climate control system at the Valle Guerra storage area.

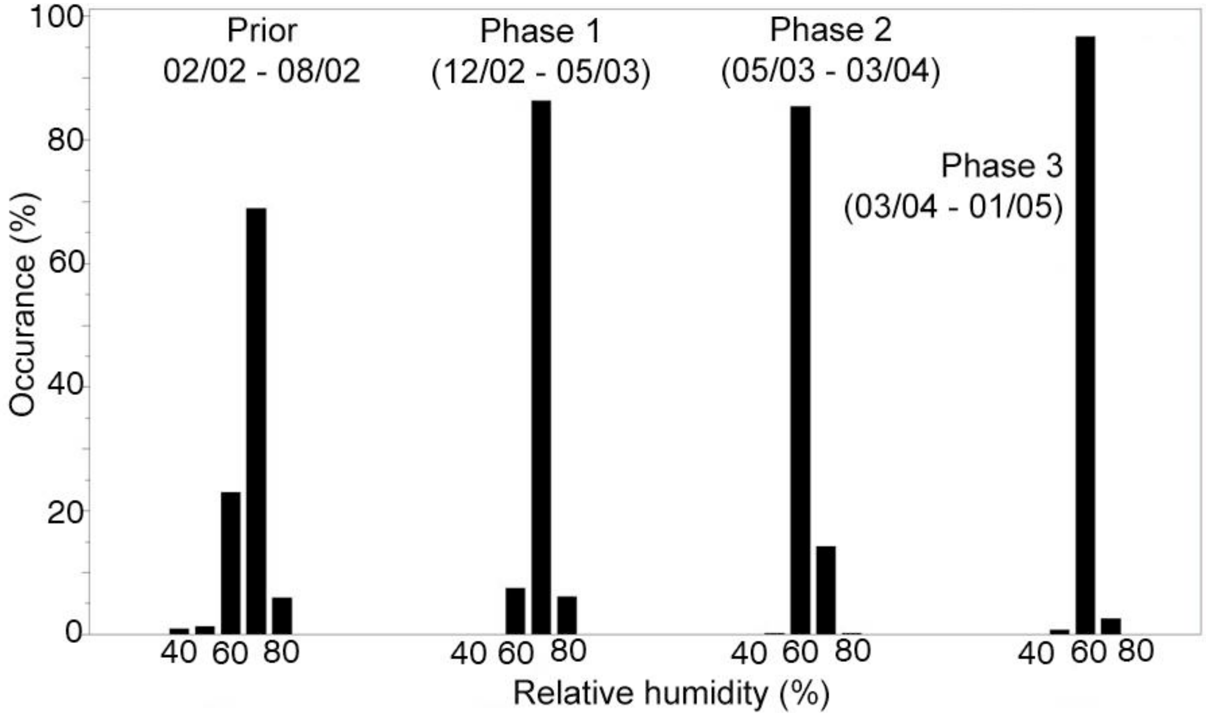


Figure 4

Histograms of RH in the Valle Guerra storage area before and after the installation of a ventilator- and heater-based climate control system.

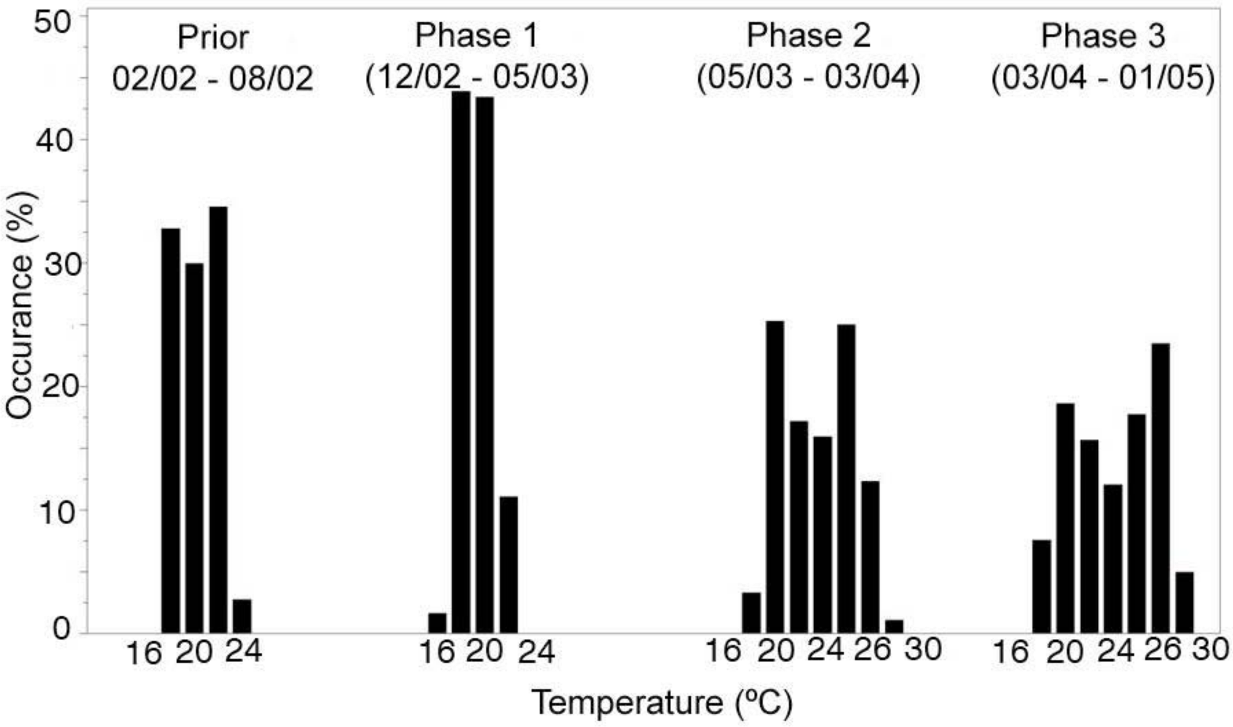


Figure 5

Histograms of the temperature in the Valle Guerra storage area before and after the installation of a ventilator- and heater-based climate control system.

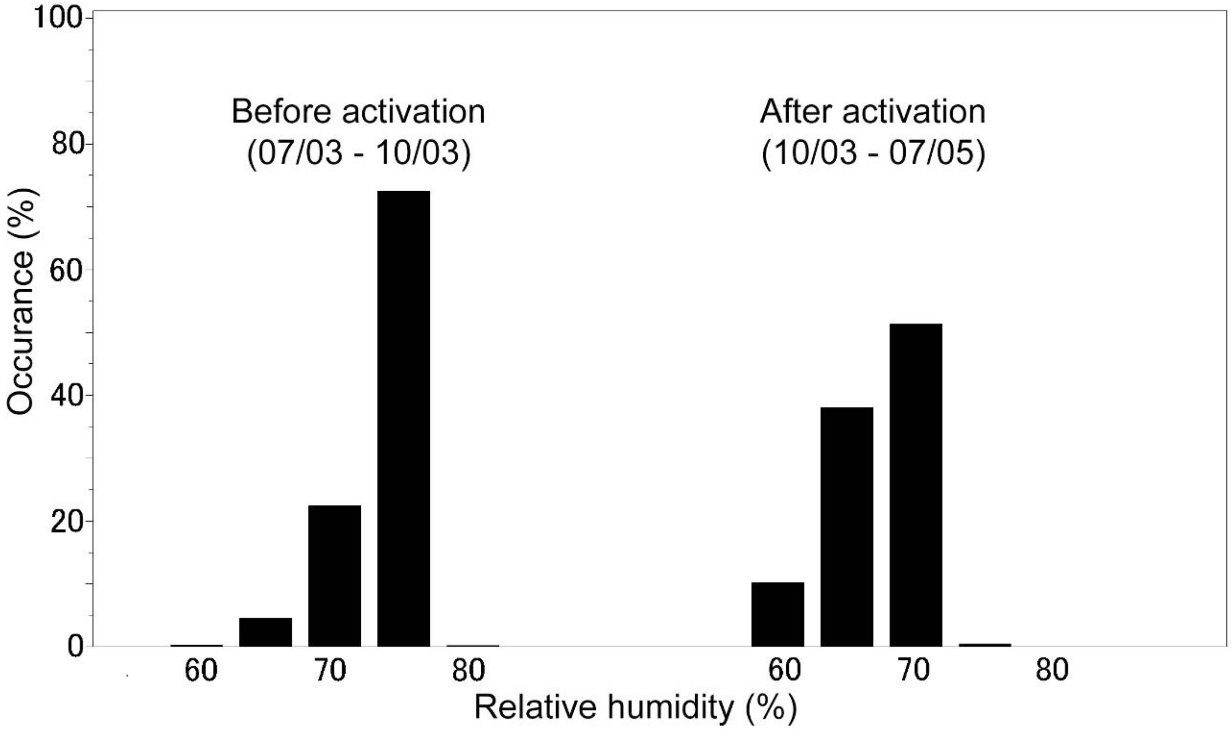


Figure 6

Histograms of RH in the ethnographic storage area of the Emílio Goeldi Museum in Belém, Brazil, before and after the installation of a ventilator- and dehumidifier-based climate control system.

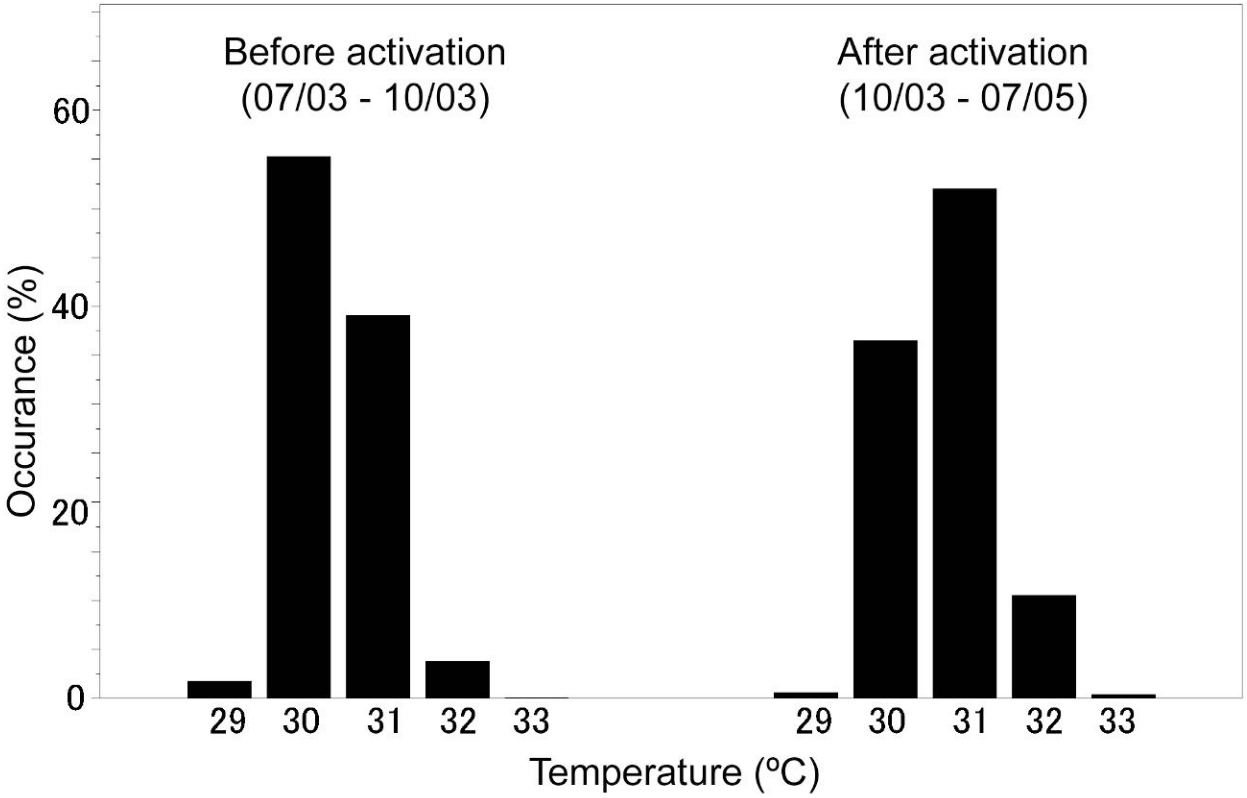
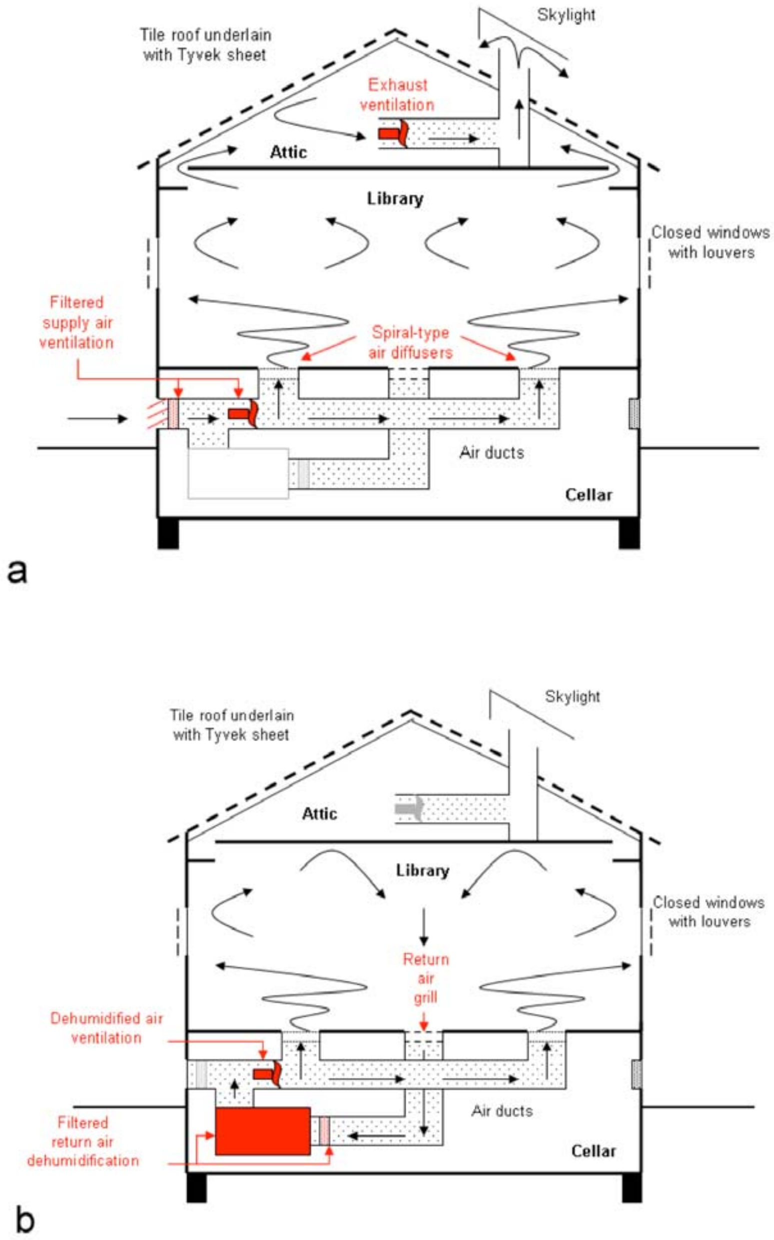


Figure 7

Histograms of the temperature in the ethnographic storage area of the Emílio Goeldi Museum before and after the installation of a ventilator- and dehumidifier-based climate control system.



Figures 8a and 8b

A climate control system installed in Casa de Rui Barbosa, Rio de Janeiro, Brazil. Drawings show the ventilation mode (a) and the dehumidification mode (b).

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