Low-Cost Climate Control System for Museum Storage Facility on Tenerife Island

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ABSTRACT: The collection storage facility of the Government of Tenerife occupies a contemporary four-story concrete building located on the northeast hillside of the island where the climate is cool and humid throughout the year. The 437 m^2 space is divided into five rooms with windows located on the northwest and northeast walls. Prior to the installation of a climate control system, the storage area was often humid with a history of fungal attacks in the collection.

A unique climate control system installed in the storage facility consists of humidistatically controlled sets of supply and exhaust fans, and convective heaters. Based on authors' conceptual design, a local HVAC company carried out the detailed design and installation of the equipment. The climate system has been in operation since August 2002. The relative humidity has been maintained below 65% with daily variation of less than 10%, while the temperature has varied between 18 and 30°C throughout the year. Both the capital and operational costs have been estimated to be less than one-fifth of a typical air-conditioning based system. This paper describes the design concept, detail design and various aspects of the system's performance as well as installation and operations experiences.

Keywords: energy, sustainable, climate control

1. INTRODUCTION

Improved environmental conditions are needed for the comfort for staff members and visitors in cultural institutions. Coupled with the need for preventive conservation of collections, many cultural institutions recognize the importance of installing climate control systems. However, there are many variables, such as the primary objective, targeted conditions, project budget, operational budget, and the adaptability of the building to a climate control system that need to be identified and answered before an institution can decide how to move forward. Depending on a combination of these variables, a typical air-conditioning based climate control system may not be the best choice for an institution/building. Improper selections of a climate approach can lead to not only achieving less than a satisfactory environment but can also lead to collection and/or building damage, not to mention large energy bills.

Recently, simple and low-cost climate control systems consisting of sets of supply and exhaust ventilators and convection heaters or dehumidifiers controlled by humidistats located inside and outside buildings were investigated for use in the preservation of cultural heritage collections and buildings which house them in hot and humid climates. [1, 2, 3] The approach focuses on the control of relative humidity for preventing the threat of fungi and bacteria to collections while allowing the temperature to vary. Therefore, these systems may not be suitable for collections sensitive to large temperature variations or which are sensitive to a higher temperature environment.

Several experimental designs based on the above concept were tested in two historic buildings in two different climatic regions. These tests showed successful control of relative humidity for collections while preserving the building from the impact of installing an air-conditioning based system. Monitoring microbial activity and dust levels indicated significant reductions of both as a result of the installation of such a climate system. These successful trials led us to test the practicality of the concept in a museum storage with a museum organization using a local architect and engineer.

2. METHODOLOGY

The principles of technologically and economically sustainable climate improvement strategies focusing on the preservation of both cultural collections as well as the buildings that house them was described in [3, 4]. The procedure for applying the principle to an existing collection/building is as follows. First, we will reduce the infiltration of outside humid air by sealing the building envelope as tightly as possible, and thermally insulating the building fabric, if possible, to reduce heat loss. These simple procedures will improve the stability of its climate and maintain a dry climate, providing that the moisture source is not located within the building.

The climate control system would be installed to either ventilate the building with outside dry air to remove moisture in the collection/building; or heat the space to reduce relative humidity, depending on the outside climate. Convective heaters would produce heating, and pairs of supply and exhaust mechanical ventilators would perform the ventilation. The procedure would allow us to maintain relative humidity in the building at less than 70%, which is the threshold value for arresting microbial activity – the major deterioration mechanism in hot and humid regions.

3. Site, Building, and Collections

Site

Tenerife Island is located in the Atlantic Ocean close to the northwest coast of Africa in a subtropical climatic region (type Csb according to Köppen classification), which determines its warm winter temperatures and sparse irregular rainfall. Northeast winds originate in an anticyclone position most of the year over the Azores which moderate the temperature and increase relative humidity. These humid winds collide against the north hillside of the island, producing a permanent ring of clouds between 600-1800 m altitude, where the air is cooler. The island is also affected by a cold marine current that freshens the ground atmospheric layers, dropping daily fluctuations of the temperature, reducing rainfall and raising relative humidity levels. This common climate only varies when winter storms coming from northern Europe reach the island, causing most of the annual rainfall, or when southeast winds carrying sand from Africa produce typically dry hazy weather.

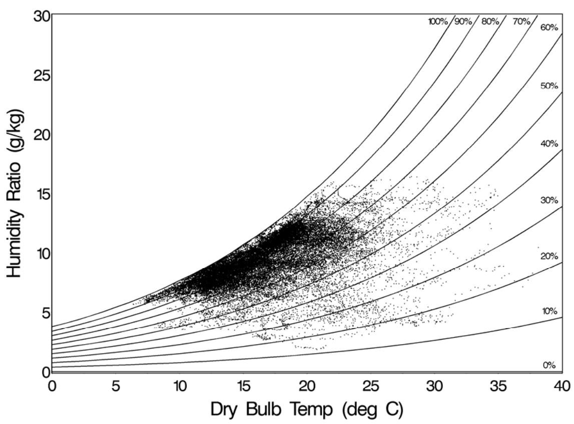

Figure 1: Temperature, relative humidity, and humidity ratio of San Cristobal de La Laguna, Tenerife Island recorded in 2001 - 2002 plotted on a psychometric chart.

The storage facility for the Anthropological Museum of the OAMC (Autonomous Entity of Museums and Centers supported by the Island Government) is located in Valle Guerra, a rural village on the north side of Tenerife, 195 m elevation, 4 km off the coastline and approximately 20 km northwest of Santa Cruz de Tenerife, the island's capital. Here winters and summer temperatures are extremely mild. January and February are the coolest months with average temperatures around 15°C. July, August and September are the hottest, with average daily maximums around 28°C. The average relative humidity is 67.6 % with the highest levels recorded in late autumn and winter. The temperature and relative humidity recorded in the city of San Cristobal de La Laguna, a town near Valle Guerra, are plotted on a psychometric chart. (Figure 1) The annual average of precipitation is 214 mm, with rainfall concentrated during winter and early spring. [5]

Figure 2: The museum storage is located on the lowest floor level where cars are parked along the side of the building. This is a view from the north.

Building

The storage facility occupies the second and third floors of a contemporary four-story, single wall, concrete building (Figure 2), built as a multi-purpose structure along a busy local road in a rural area. As it was built along a sloping hillside, only the two top floors of the building are above the grade on its street side; however, all four floors are exposed to the air on the opposite side. The control of its climate was considered only for the first floor. The southeast side of the floor facing the road is a few meters below the grade, while the north and west sides are entirely open to sea breeze. There are no stairs connecting the first floor to other floors; access is only through three doors along a narrow paved road on its west side (figure 3). Single pain, aluminum framed windows are located on the north- and west-facing walls.

The storage area encompasses approximately 440 m^2 with a 3 m high ceiling and is divided into five rooms. Rooms A and B are the largest (Figure 3). They are connected by doorways in the walls and have one window each on the west side. Rooms C, D and E are lined up against the north wall. Except for C, which can be entered from the outside, the rooms can be entered through a narrow door that connects them with room B. Each room has a window opening on its outside wall, while D and E have additional windows opening through their interior walls to room B. There are three access doors to the storage: a narrow door in room A, one in room B, and a large metal garage door with a small door embedded in room C.

The space was refurnished with open steel shelving system in rooms A and B, and wooden wardrobes fitted in rooms D and E. The collections were distributed on the shelves throughout the rooms, according to the criteria of easy access. Small and medium size objects such as pottery, basketry and household items were placed in room A, the narrowest and most difficult to access. Large and bulky objects were located in room B, the largest and easiest to access from outside; and the Canaries textiles (dresses and daily clothes) collection was placed in rooms D and E. These two small rooms, although noticeably more exposed to the outside climate than other rooms, were self-contained and could be easily isolated from the others if required, for instance to prevent an insect infestation from spreading. Climate monitoring proved that rooms D and E were 1° to 2°C cooler, and therefore about 5% RH more humid than rooms A or B. However, we never experienced fungal, mold or insect problems in these rooms. Microbiological analysis showed that contamination inside the wardrobes is low; outside the wardrobes is similar to the other rooms. [6]

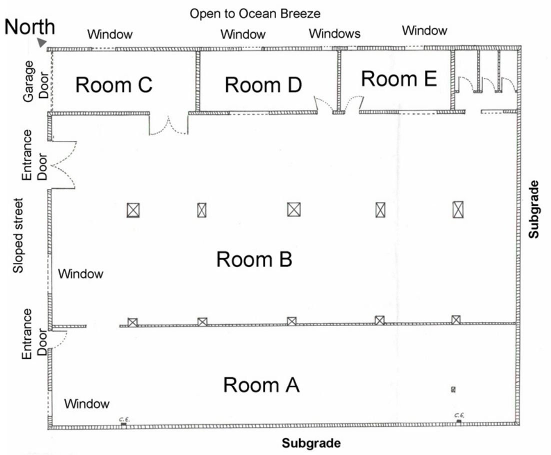

Figure 3: Floor plan of the museum storage in Valle de Guerra.

Due to its large access door, room C was considered to be too exposed to the outside and too dusty to be used as a storage space. Therefore, it was designated as an objects reception and quarantine space.

Collections

This storage facility houses a collection of folk artifacts from the late 19th and 20th centuries, which documents traditional Canarian activities in agriculture, small industry and handcraft. It also has important collections of peasant garments, textiles, pottery, basketry and furniture. There are about 3,000 objects made with diverse technologies and using a large range of materials, prevailingly those crafted with poor organic materials such us sapwood, sticks, leaves, hide, paper and leather. The number of items having metal in their structure is also important. Most of these objects are quite worn and battered because they were used intensively in daily labor until nearly broken and then neglected in cellars, attics and barns. In general these objects are not sensitive to higher temperatures that accelerate the chemical aging process. However, they are prone to biodeterioration, fungal attacks, bacteria and insect infestation as well as high levels of relative humidity that can promote corrosion.

Only textiles and garments are stored in wooden wardrobes, drawers and acid-free cardboard boxes to shield them from dust deposition. The rest of the objects are directly placed on open metal shelving. Therefore, the main concern for these objects has been to maintain an environment free of dust.

The climate improvement project

In 1999 the storage suffered a serious insect infestation that affected a quarter of the collection. It was assumed that the infestation was related to increased fungal activity in the storage. Therefore, it was clear that preventive conservation measures should be taken and the climate controlled. As the building was not owned by the museum, the OAMC immediately dismissed any large investment and special attention to control its environment due to the anticipated high cost of such an installation.

The installation cost of a typical air-conditioning based climate control system can range from 150 €/m^2 for the simplest (as those installed in the organization's offices) to 400 €/m^2 for the most complex system (as was installed in the Museo de la Naturaleza y el Hombre exhibition rooms). This high cost is due to some extent of having to transport every single piece of machinery from mainland Spain. Maintenance is also expensive. The annual maintenance cost of the Museo de la Naturaleza y el Hombre air conditioning system is 9,000 €.

In short, financial restrictions forced the OAMC to look for an inexpensive, flexible and easy-to-maintain climate control system that would be able to keep the climate (relative humidity and temperature levels) suitable for preservation to prevent fungi and bacterial infestation. Furthermore it should allow for comfort for those museum staff performing temporary work in the space. Because of these requirements a climate control system designed for and tested in the Historic Archive at the municipality of San Cristobal de La Laguna [2] was considered to be a suitable alternative to conventional air-conditioning systems.

Conceptual Design

There were a few restrictions for developing the design for the climate control system at the Valle Guerra storage. Since the building wasn't owned by the OAMC, we were not allowed to modify the existing building envelope. Therefore, we could not create large openings in existing walls or permanently close existing openings such as entrance doors.

Since there was no possibility of installing windows on either the southwest or southeast wall to achieve cross ventilation for rooms A and B, a concept was developed to take the supply air from the northwest wall and transfer it via a long duct to the southeast end of the room where it would be released into the space. The exhaust ventilators would be mounted on the ceiling near existing windows of the northeast wall.

We could produce a large climate zone in the storage by removing the doors and windows between rooms B, E, and D. Room A could not be included in the zone due to a skewed location of its doorway to room B; and room A had the most stable and dry environment due to its largely below the grade boundaries. Therefore, we created two zones, room A, and the remainder of the storage area.

Engineering Design and Installation

Once the conceptual design for the climate control system was completed, a local heating, ventilation, and air-condition (HVAC) company was contacted to produce a detailed engineering design and the installation of the mechanical system based on the above concept. This turned out to be a more difficult task than anticipated. Although there are several HVAC companies on Tenerife Island with extensive experience in designing and installing air conditioning equipment, their engineers found it difficult to accept the approach of the project. One issue was proposing to control relative humidity by using controlled ventilation and heating rather than cooling the air and removing moisture from it. Therefore, the start of the project involved intense negotiations with local engineers who felt reluctant to embrace this alternative approach that differed significantly from their normal design.

Another problem was that the engineer proposed the use of high speed jet nozzles for turbulent mixing of ventilating air. Although guidelines have not been published on the allowable maximum air velocity on surfaces of objects, lower flow velocity and less turbulence are recommended to prevent stressing of objects. Therefore, a slow laminar flow should be used to provide gentle cross-ventilation. This would require the installation of long ducts to transport the fresh air to the other end of the rooms. This disagreement resulted in a change order during the installation that caused additional expense and delay. Once the HVAC company was selected and the mechanical layout settled, several meetings between the authors and the project engineer were held in order to develop an installation schedule and supervise its progress. Despite of all these meetings, detailed instructions and close supervision, it still required the authors' constant review and supervision for the project details to be correctly executed.

Climate Control System

The climate control system for Valle Guerra storage, installed in August 2002, consisted of three supply (3,500 m^3/hr each) and three exhaust (3,500 m^3/hr each) ventilators, and five convective heaters (350 m^3/hr, 3030 W each) that are controlled by two interior and one exterior humidistats. The supply air ventilators were placed inside of the building, bringing filtered outside air through ducts mounted under the ceiling, and fresh air is released from diffusers at the other ends. Each supply ventilator had an insect net, washable metal filter, and a disposable G3-type particle filter. The venting air, after flowing through the rooms A and B, was collected near the ceiling of rooms C, D, and E through unducted exhaust ventilators. (Figure 4) Gravitational-type shutters were installed on their exhausts. Five convective heaters connected to the humidistat were initially located in corners of rooms A and B.

The climate system has been in operation since the installation with several improvements made along the way, while various aspects of its performance have been monitored and analyzed during the same period. During the commissioning stage, we found that the simultaneous operation of three exhaust ventilators produced a large negative pressure in the storage; therefore, the unit in room C was taken offline. And a connecting door between rooms B and C was kept closed as room C became a quarantine space as described earlier.

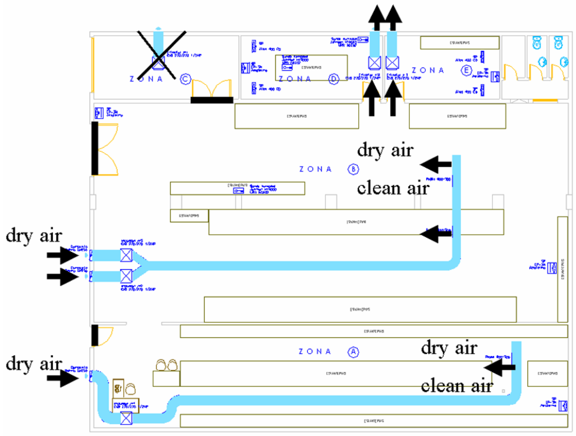

Figure 4: The operation of the climate control system during the ventilation mode (RH_{out}<70% and RH_{in}>70%)

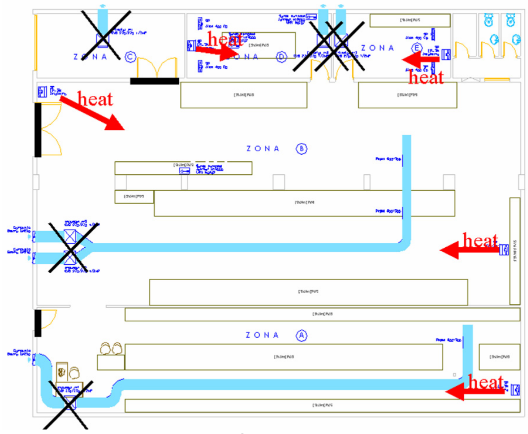

Figure 5: The operation of the climate control system during the conservation-heating mode. (RH_{out}>70% and RH_{in}>70%)

Even with sealing and insulating windows in rooms D and E, the temperature remained a few degree Celsius lower than room A; therefore, two of the convective heaters were moved to those rooms. (Figure 5) However, heating in the rooms produced a large (10-12°C over the 3 m height) thermal stratification resulting from cold floors. A floor-standing oscillating fan was added to operate with the heater to eliminate the stratification and distribute the heat throughout the rooms.

Temperature and Relative Humidity

Figures 6 and 7 show histograms of temperature and relative humidity in room D, the worst climate in the storage, during various phases of the project. Phases 0 and 1 correspond to climates prior to the installation and after the installation but prior to commissioning the climate control system, respectively. During Phase 3, the system was set to maintain 60-70% RH, and 55-65% RH during Phase 4.

Prior to the commissioning of the system, Phases 0 and 1, the temperature was stable at 18–24°C, while the relative humidity varied between 60-80% RH. Most significantly, relative humidity was higher than 75% (when fungi become active) for nearly 7% or 25 days a year. This environment indicated a significant risk to organic materials in the collections, such as textiles, plant and vegetable fibers, leather, and wood.

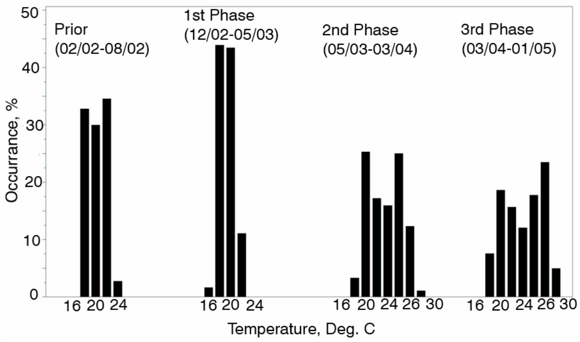

Figure 6: Histograms of the temperature in Valle de Guerra storage during various phases.

Once the climate system began to operate correctly, the temperature variation widened to 18-30°C, which is a 6°C increase at the upper limit. However, the relative humidity variation narrowed to 55-65% as it was set for. And conditions of higher than 75% RH were completely eliminated. Daily variations of RH were also reduced from 5-20% to 2-6%, indicating significantly improved stability of the relative humidity, ultimately improving protection from mechanical damage to organic objects.

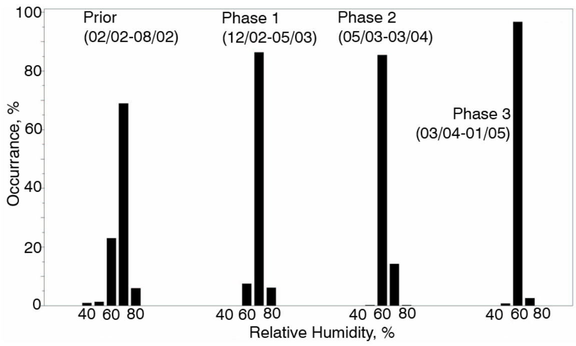

Figure 7: Histograms of the relative humidity in the Valle de Guerra storage during various phases.

Noise

The noise level ranged from 56 dB at approximately 1 m and 54.6 db at 4-5 m from the supply ventilator. The level was 0.3-0.6 dB higher in room B than A since there were two supply ventilators in room B. However, at the diffuser end, the noise level was reduced to 47-48 dB. At the intake side of exhaust ventilators, it ranged from 61-62 dB at 1 m and 55.5-55.9 dB at 5 m from the ventilators. These high noise levels were due to the exposed installation of the ventilators at the intake ends.

Microbs and Dusts

The microbiologist reported that microbial contamination in the storage was significantly reduced since the installation of the climate control system, and has been maintained at a low level ever since. [6] The conservator also reported substantial reduction of the levels of dust deposition in the storage and no deterioration or changes to the collections. [7]

The installed system has been robust, and the only maintenance performed over two-and-a-half years of operation has been the replacement of filters and the annual calibration of relative humidity sensors.

Although the storage was never designed as a permanent workspace, issues of human comfort were also addressed. High noise levels and high temperatures during summer were inhospitable to workers and needed to be resolved in order to use it as an extended work area or a permanent office space.

4. COSTS

The engineering design, equipment and installation of the climate control system cost approximately 18,600 €. While the system was being installed, several modifications to the building envelope were made to improve its isolation from the outside climate (so the airflow could be controlled during ventilation and keep heat in the building during conservation heating). External windows were either converted to supply or exhaust openings for ventilators or we improved the airtight-ness with sealing materials. All doors were fitted with additional seals and gaskets. Doors to rooms A and B from the outside were permanently blocked and a new airtight door was installed to segregate the toilet area from the rest of the storage rooms. This work was carried out by OAMC maintenance staff; therefore, only the cost of materials was available and reported to be approximately 1,200 €. In addition, the OAMC paid approximately 400 € to the utility company for upgrading the allocation of the electrical power in the storage. Therefore, the total cost of the project became approximately 20,200 € or 46 €/m^2, one-third of typical air condition system for OAMC's offices and approximately one-ninth of the cost of the most expensive system installed in OAMC's museums.

Figure 8 shows the composite plots of relative humidity in room B and average daily cost of electricity use in the storage. The cost includes general energy use (lighting and other domestic electrical use) that may vary from month to month depending on conservation/cataloguing activities by the OAMC staff. There was a jump of the energy use from less than 2 €/day (@ 0.08 €/kW-Hr) prior to the installation to 4-6 €/day during Phase 3 operation, when the relative humidity was controlled between 60 and 70%. The cost of electrical usage further increased to 6-8 €/day or 6.6 €/m^2/yr, but still is only one-fifth of the energy cost of a typical climate control system in museums which consume approximately 30 €/m²/yr.

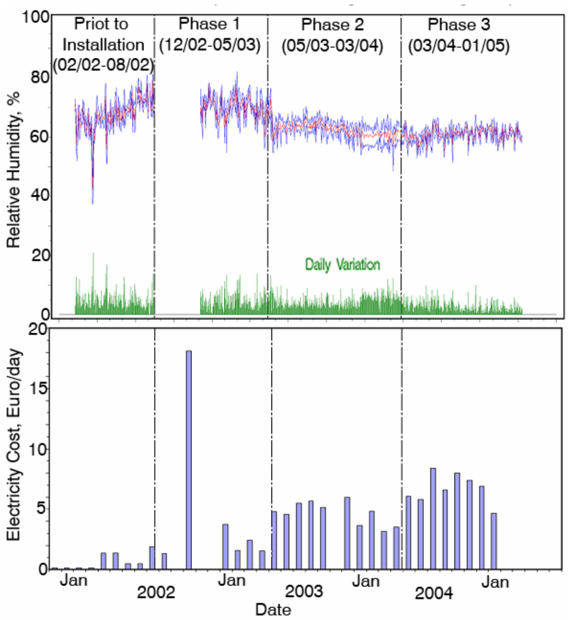

Figure 8: Comparison of relative humidity variation in room B of the storage (top) and its average daily energy (operational) cost for each month.

5. CONCLUSION

After the installation of the climate control system, proposed improvements in the collections' environment have been achieved. Relative humidity has been maintained between 55 and 65% while the temperature ranges from 18°C in winter to 30°C in summer. The most remarkable observation is that dust levels have been substantially reduced. This is an important achievement, taking into account that the storage is surrounded by agricultural area and along a busy road. Furthermore, daily fluctuations of relative humidity have been reduced to an average of less than 5% and rarely exceeding 10%. The benefits of having such steady relative humidity will be noticed over the long-term, especially for objects made of wood or vegetable fiber. Since the initial operation of the climate system, we have not seen any deterioration or changes among the stored objects.

Although the targeted environment was for the preservation of the collection and not for the human comfort, it was sometimes uncomfortable for staff members working in the storage facility. First, the ventilators are quite noisy. No attempt to reduce this noise has been made, since this is not heard outside the storage and is produced only intermittently when the system is running. Some design improvements should be considered to reduce the noise level if the area will continue to be used as a regular workspace.

The museum staff also expressed discomfort working in the sealed space with artificial light for extended periods of time. Therefore, tasks needing be performed in the storage should be designed for only short amounts of time in the space. A suitable work area could be created outside the sealed storage space, such as room C, for work that requires an eight-hour day. Otherwise, periodic short breaks should be planned in the workday.

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