Museum Passive Buildings in Warm, Humid Climates

By Franciza Toledo

Introduction

Old and new buildings can be climate-responsive and able to attenuate exterior conditions. Historic buildings, in particular, were conceived to deal with climate passively, through proper design and adequate building features and materials. However, with time and changes of use, the architecture of such buildings is commonly altered. Buildings acquire new uses, and original spaces as well as constructed details are modified to suit new physical and spatial needs. Changes in buildings can be made to both the interior and the exterior. Interior changes are mainly due to new uses, and they often occur along with replacement of old materials, devices, or design details considered obsolete; applications of new finishes; reduction of ceiling heights; removal or introduction of partitions; blockage of circulations and openings; and, depending on the new function, increases in the number of users. Changes in the surroundings might be due to urban growth and regulations, reduction of vegetation, alteration of ventilation and solar incidence paths, and, mainly, air pollution.

In such cases, the original building's climatic performance is therefore hindered and in need of improvement. In the case of museums, these improvements should aim at climatic stability and material safety; in warm, humid regions, improvements should also aim at reducing heat and moisture indoors. And the key to achieving efficient climate control is to maintain interior conditions close to the exterior ones.

Instead of paying attention to a building's original design and use, conservation architects tend to address museum building pathologies only, when they result either from natural aging or from lack of maintenance. When dealing with preventive conservation policies, architects have overlooked the building's original architecture and use, even though they might be potential tools for a better understanding and control of the indoor climate in museums and archives. A recent literature review shows that most museums' climate control projects and building evaluations have followed a remedial approach rather than a preventive one. Museum buildings have been assessed because their decay processes may cause harm to collections and users and therefore need to be remedied. The possibility of rescuing or rejuvenating past indoor environments or passive building features—or even devising new elements and setups that could enhance their climate performance—is therefore disregarded. A better understanding of a building's design and fabric, as well as an understanding of how it was primarily used, can lead architects to retrofitting, minimal intervention, energy saving, and sustainability.

The application of passive building designs to create conservation environments has been increasingly applied in archives and museum storage areas in both temperate and cold climates because, in such spaces, human health and comfort are secondary issues, so air renewal is kept to the minimum necessary to exhaust the pollutants generated by the collections themselves. It is therefore easier to keep exterior climate fluctuations and cold away from the building, by either applying thermal insulation or by increasing a building's thermal inertia. Museum exhibition spaces, in contrast, continue to rely, to a greater or lesser extent, on HVAC systems, because the architectural design to impress the public has become more important than satisfying conservation and comfort needs, which are cared for or compensated for mechanically (Padfield and Klenz Larsen 2004).

Many museums in warm, humid regions are housed in old, naturally ventilated buildings, made of traditional materials and with traditional techniques, and it is likely that, just by enhancing their original architectural features or by manually controlling their ventilation regimes, climate control can be achieved for both visitors' comfort and material conservation. Passive buildings, particularly the ones benefiting from natural ventilation, have been designed for museum visitors and staff but not for collections, given that the approach brings light, pollution, and climatic instability into the building. When, in order to control and stabilize interior climate, ventilation is reduced inside storage spaces, it can be very difficult to prevent heat and moisture from building up indoors without some mechanical aid (Maekawa, Toledo, and Arraes [2006]).

Architectural qualities or potentialities of both old and new museum buildings have been recently highlighted by computer simulations that allow for past climate and energy performance evaluation of several building types of different ages. Computer simulation programs to evaluate buildings' energy performance—despite their commonly criticized lack of exactness—can produce scenarios that may lead to the best possible solution for museum building improvements and interventions (Taylor et al. 2005; Toledo 1999).

Regardless of what is at stake, if museum buildings need some mechanical aid to control indoor climate, mainly because of exterior changes (urbanization), it would be even more efficient if the original building's design could be reviewed and rejuvenated. Prior to intervention, buildings should be assessed as potential shelters for visitors and artworks. Instead of looking for apparent flaws, architects need to look for inherent architectural qualities. Passive design with climatic responsiveness should be pursued in all building types, for there is now an urgent worldwide demand for energy saving and sustainability.

Climatic Stability and Reduction of Heat and Moisture Indoors

Climatic steadiness is a natural feature of warm, humid climates. Daily as well as seasonal variations are small, and comfort is mainly achieved by the shading and ventilating of buildings. Precipitation is high throughout the year, and wind velocity is generally low (Gut and Ackerknecht 2005). Daytime temperatures vary from 20°C to 32°C, while nighttime values range from 21°C to 27°C. Relative humidity (RH) values range from 55% to 100%, the mean value being around 75%. Because of the generally cloudy sky, heat is not easily dissipated in the atmosphere, so the key issue, for both comfort and conservation purposes, is to reduce heat and moisture gains indoors. In the case of a museum or historic building, this approach may mean reducing human comfort levels slightly, increasing the number of climate control zones and cooling opportunities, and improving the energy efficiency of the building (Park 2004).

It is known that museum collections acclimatize to their immediately surrounding environment, as long as it is stable. Climatic stability is more important than the internationally known and still-recommended standard climatic values. The notion of an "ideal museum environment" is therefore relative, and both architects and conservators, when designing or adapting a building to house a museum collection, should first pursue indoor climate steadiness.

For the sake of the building fabric, the maintenance of interior conditions close to exterior ones can be advisable. Architects should aim at minimal intervention—only enough to keep limit values and prevent material deterioration. An indoor environment that slowly varies with the outdoor conditions is less harmful to the building fabric, and the building itself normally provides some climate tempering, which may be sufficient most of the time. Some mechanical services can be provided to moderate extreme climate conditions (Maekawa, Carvalho, and Toledo [2006]; Park 2004; Holmberg and Burt 2000).

Climate-Responsive Design and Fabric

The building design and the space it encloses are seldom explored as potential tools for a beneficial indoor environment. Space in its three-dimensional aspects is seldom discussed when the evaluation of a building's climatic performance takes place. The shapes of rooms, the heights of ceilings, the types and locations of openings, roof forms, and so on—which are so important with regard to hot air movement and stratification—are often overlooked. Yet they all play a part in the conditioning of the indoor climate, and these factors should be placed in context when an environmental management plan is to be produced. The three-dimensionality of a building is commonly taken into account when air volume is a necessary value for the calculation of air renewal indoors. Maintaining ceilings high and permeable and windows operable helps alleviate heat inside buildings.

Reduction of Heat and Moisture Gains

If air temperature and RH are to be reduced indoors, some architectural features should be highlighted. The positioning of the building with regard to the path of the sun, the prevailing winds, and the driving rains, together with a good design and careful location for the openings, can lead to improved zoning and distribution of rooms, according to their functions and climatic requirements. A combination of shade and ventilation (either natural or controlled) also plays a key role in the process.

Natural and Controlled Ventilation

A dependence on entirely free-running buildings (King, Daniel, and Pearson 2000) is still being adopted in museum exhibition spaces in warm, humid regions, where different climatic needs should be combined and conciliated: those of the buildings, collections, and visitors. The staff takes an active role in the operation of such buildings—e.g., by opening and closing windows at appropriate times (of the day or of the season), by using movable shading devices, or by mopping the floors with water when the weather is too dry (Zhou 1988; Ke-Jian 1988; Jahan 1988). However, the most challenging issue in such regions is to use natural ventilation and to avoid, at the same time, insects and air pollution indoors. How to create the necessary openness and free air circulation required for human comfort, without allowing in such detrimental factors for collections conservation? In small Asian museums, this goal has been accomplished by a careful control of natural ventilation and by the creation of microclimates for objects on view.

Attempts to run air-conditioning systems in such warm, humid museums have failed (Daniel et al. 2000; King, Daniel, and Pearson 2000). Some historic buildings, made of either brick or stone masonry, with and without mechanical climate control systems, including conservation heating, were monitored in Australia over the past ten years. Data showed that when those systems fail, the resultant environment is more damaging than the natural conditions: condensation and fungal outbreaks on surfaces are the most common risks. In the case of a recent instance of conservation heating, data registered climate variations larger than the natural ones (Daniel et al. 2005).

When a building is modified to house a museum, where complex and sometimes conflicting climatic requirements need to be addressed, attention should be given to how air movement is handled. Museum buildings comprise basically three spaces: areas for storage, exhibition, and service (foyer, bookshop, restaurant, etc.), with three different climatic requirements, which can also be limited to three ways of handling air movement or infiltration. Storage spaces where collections are kept require minimal air renewal, so passive control is possible in both temperate and cold climates. In warm, humid regions, however, a mixed control—i.e., a combination of passive design and air dehumidification and recirculation—seems to be the only solution so far. As for exhibition spaces, when the collection is encased (in microclimates), passive climate control is possible, and natural ventilation can be used. If the collection is directly exposed to visitors, such as in a house museum, a mixed control, consisting of passive building improvements coupled with filtered/forced ventilation and a bit of cooling, is advisable (Maekawa, Carvalho, and Toledo [2006]). As for service areas, depending on the exterior climate, spaces that are either free-running or climatized (heated or cooled without humidity control) can be options.

Similar climatic conditions allow for the use of similar building materials, shapes, volumes, and techniques, all of which are closely connected, contributing to define some common architectural types that can be found in different places around the world (Sangiorgi 2004). Buildings built in warm, humid regions have physical similarities, including ventilated pitched roofs, long eaves, openings on all facades, stilts, and above-grade basements separating buildings from humid grounds.

Stilts and Above-Grade Basements

Transitional spaces act as buffering zones and are always useful between conditioned and unconditioned environments. Ventilated attics and basements, corridors, or *chemins de ronde,* as well as vestibules, are always useful as air-cushion areas (G. de Guichen, pers. comm., 10 Nov. 2006).

Stilts are largely used in flat areas prone to floods. In Brazil such constructions are found at riversides. Native peoples along the Amazon River build their houses on stilts. Examples can be seen at the Museu do Marajó, on Marajó Island, Pará, Brazil (fig. 1), at the storage building of the National Museum in Abidjan, Ivory Coast (figs. 2a and 2b), both built in the 1990s, and at the Museum of Colonial History in Aba, Nigeria, built in 1903 (Ughenu 2000).

The storage of the National Museum in Abidjan was designed by Gaël de Guichen, during the ICCROM PREMA (Prevention in Museums in Africa) 90/91 course, to deal with the local warm, humid climate passively. The building is rectangular, measuring 20 x 9 x 3 m, and raised on stilts 70 cm from the ground, with a ventilated (trellised) and accessible attic space. Its light-colored metal roof, installed over wooden trusses, has long eaves to prevent rains on the walls. Upper and lower narrow trellises along the longitudinal walls are provided with galvanized steel mosquito nets (1 mm). Interior air circulation is assured by five fans evenly distributed to prevent stale air. The climatic performance of the storage building is still to be assessed and evaluated (G. de Guichen, pers. comm., 10 Nov. 2006).

Many nineteenth- and twentieth-century Brazilian buildings rise on top of above-grade basements (fig. 3). These buildings, the products of urban development and the sanitation policies of the time, are defined by Nestor Goulart Reis Filho as transitional, evolving from colonial one-story houses to slim, urban multistory houses, in which basements acted as buffering spaces, protecting the buildings from rising damp, insects, and rodents (Reis Filho 2004).

Basements, although inadequate because of their intrinsic coolness and dampness, are often used as museum storage areas. Remedial measures, such as making the walls impervious to water penetration, in addition to altering the original function of those spaces (as buffering or sacrificial ones) just conceal the inadequacy of the intended use.

High Permeable Ceilings

Hot air generated indoors rises and stratifies on upper parts of buildings, and when there are gaps on ceilings, it can be dispersed through the roof structure. It is common to see ample rooms with high ceilings in most Brazilian historic buildings. Casa de Rui Barbosa, a house museum in Rio de Janeiro, for instance, has two types of permeable ceilings: one over the main rooms is open on the edges, through a recess in the ceiling panel from its cornice (in the 1990s, the function of such an architectural feature was hindered by the application of Tyvek on the roof, but it was recently retrofitted through the installation of a mechanical exhaust system in the attic space of the house-museum, forcing hot air out of the building through a skylight), while the other, over the kitchen, is simply a trellis that allows hot, humid air and odors to dissipate rapidly through the roof (fig. 4). The importance of maintaining surface temperatures close to those of the interior air is to avoid convective motions that carry with them airborne particles, which in turn contribute to the darkening and soiling of vents, walls, and ceilings (Camuffo et al. 2004).

Double or Triple Opening Frames: When the Users Should Play a Part

The shape, distribution, and details of openings in buildings in warm, humid regions are important in the control of natural light and ventilation. Normally the design of doors and windows is quite elaborated: many consist of three different barriers against the exterior climate: an inner wood shutter, for both shade and security; an intermediate glass pane, for natural light; and outer louvers, allowing for shade and natural ventilation while maintaining privacy. Double frames, with a combination of the above devices, such as those on a listed building in Recife, Pernambuco, in northeast Brazil, are more commonly found (fig. 5). Again, such passive architectural features require users to make them functional. There may be a time for each of these three elements to be open or closed, depending on the period of the day and on weather conditions. This daily maintenance routine can be performed by anyone, given that only basic knowledge about sun incidence in summer and winter and the direction of prevailing winds is needed.

Designed by Oscar Niemeyer in the late 1950s, the Palácio da Alvorada, the Brazilian presidential palace in Brasília, is, in a sense, a house museum. It is a shallow rectangular building that faces east-west; it has movable glass panes protected by a deep veranda and vertical movable louvers, designed to be arranged according to sun incidence and room function. The glass panes were devised to benefit from lower, cooler air from the exterior, through a reversed "maxim-air" type of opening, through which hot air is exhausted through upper bascules that are controlled from below by metal strings (figs. 6a and 6b). In addition, plenty of cross-ventilation is provided when the transparent large sliding windows and doors are opened. Unfortunately, neither the building's users nor keepers paid much attention to such features, and they often complained about the heat inside the building. Thus, two years ago, a large air-conditioning system was installed in the building, and the openings are now permanently shut.

Shading Devices

Shading devices are quite efficient for reducing heat gains by buildings. The use of a sun path chart is the main criterion for the design of these devices. About 70% of the efficiency of sun breakers, or *brise-soleils*, is due to their geometrical shape and orientation, 15% to their material, and 15% to their color. In general, shading elements should be horizontal on east and west facades, because the sun is low, and vertical on north and south ones. External movable louvers transmit less radiation (0.15) than internal Venetian blinds (0.25). Horizontal elements should be separated from the walls 10 to 20 cm to allow warm air to escape and to reduce thermal bridging to a minimum. Shading materials should have the ability to cool down after sunset (Gut and Ackerknecht 2005).

External elements can be added to historic buildings, to reduce sun incidence and heat loads on facades, if they can be easily detached or retractable (Randl 2005). These devices, widely used in the United States in the nineteenth century, have been rediscovered by a growing number of builders and building owners as a very cost-effective strategy to reduce glare, heat gains, and energy costs with cooling, for both residential and commercial buildings. The U.S. government, through its preservation programs, has encouraged the installation of awnings on both historic and nonhistoric buildings, partially financing such initiatives. Research in historic archives and old photographic collections helps in the selection of the most suitable types of awnings according to the shape, scale, and location of doors and windows, as long as they comply with local municipality regulations. In the Northern Hemisphere, awnings can reduce heat gains by 65% when installed on south-facing windows and 77% when installed on east-facing ones. When used with air conditioners, they can reduce the cooling costs by up to 25% (Randl 2005). Awnings were installed at the north balcony of Casa de Rui Barbosa to protect mural paintings that used to be hit by the sun daily (figs. 7a and 7b).

Verandas are more commonly found in warm, humid climates. They have the advantage of covering most of the facades, protecting doors and windows from both sun and rain incidence. They also allow users to be sheltered outdoors, particular at night, when the winds are cooler. In different styles and configurations, they are part of the Palácio da Alvorada, the Museu do Estado do Pará, and historic chalets in Recife, Brazil.

Thermal Insulation and Inertia

If the facade is to be directly exposed to solar radiation and rains, enameled ceramic tiles—*azulejos*—as well as limewashes have been effective exterior finishes to protect external walls, since they reflect the sunlight and make the walls impervious to rain, reducing both heat and moisture indoors (see fig. 5).

The use of wall cavities (as air cushions), thermal mass (thick walls), and external reflective materials, such as whitewash or enameled ceramic tiles, can help prevent heat gains on external walls. Thermal mass or inertia is also important to provide a stable indoor environment, since the interior air temperature hardly changes. It helps maintain the building's interior cool during the day, the daily heat transfer being delayed for a couple of hours (Gut and Ackerknecht 2005).

Most of the old European architecture that was brought to the colonies in the eighteenth and nineteenth centuries is grandiose and stylish, but design adaptations were made to address the needs of the local climate, such as construction in isolation with openings on the four facades, high-pitched ventilated roofs, deep verandas, above-grade basements, and so on. Such buildings can take the form of fortresses on the coastline, or they can be churches, palaces, and institutional buildings further inland. Most of them were built with massive walls that have kept heat away from daytime users and that maintain a steady indoor climate at night, because the heat lags behind and these buildings' interiors become hotter at night, with RH similar to daytime values. Many Brazilian museums are still housed in massive old buildings, and the city of Belém, the capital of Pará, has two examples of them.

The Museu do Estado do Pará, or the State Museum (fig. 8), was designed by Antonio Landi, an Italian architect who came to Brazil in 1753 in a mission to delimit the Portuguese territory according to the Madrid Treaty. Built from 1768 to 1772, the museum was originally a palace for the Portuguese governors. It is naturally ventilated, showing architectural influences of the Italian villa, with a courtyard and loggia and thick walls. It also has a recessed veranda. Also in Belém, the Palácio Antonio Lemos, built in the nineteenth century by José Coelho da Gama e Abreu in a Neoclassical style, is also a naturally ventilated and massive rectangular building that houses the city art museum. It has thick walls and many openings on its four facades.

A major problem with massive old buildings in warm, humid regions is that their thick walls have, without maintenance, weathered over time, and now many are damp, showing water stains and contributing to increased moisture problems indoors.

Another common but not easily spotted problem is the coolness of the inner side of thick walls in the early morning hours, which may be a source of condensation, if exterior warmer, humid air penetrates the building (Gut and Ackerknecht 2005; Daniel et al. 2005; Daniel et al. 2000; Toledo 1999). Despite small differences between daytime and nighttime temperatures in warm, humid climates, nighttime air can be slightly cooler and drier (for evaporation does not take place). Nighttime ventilation was tested inside a building with high thermal inertia, and it proved also to be of benefit to human comfort during the daytime in warm, humid regions (Givoni 1994). If museums are to benefit from these climatic events, for both the comfort of users and the conservation of collections, the interior air and surfaces could be cooled down in the night and the building could be maintained partially (or completely) closed during the daytime, which is the case for the interiors of Brazilian Baroque churches.

Ventilated Roofs

In warm, humid regions, where torrential rains are frequent, pitched roofs are preferred, together with long deep eaves, external downspouts, and oversize gutters, for rains should be speedily drained away from the building's surroundings.

In spite of the rain, roofs can be permeable and ventilated. If a roof has two slopes, the sides can be screened to facilitate the exhaustion of hot air. If it has four slopes, a clerestory or a skylight helps to increase the air "stack effect." The Museu do Estado do Pará is a good example of a building with a ventilated roof. Inspired by French architecture, it has small mansards that acted as both wind catchers and chimneys, facing both the courtyard (fig. 9a) and, in the past, the streets (fig. 9b). There are currently several small raised vents along the outer edges of the chutes (fig. 9c), which act mostly as exhaust vents; they were added during a recent building intervention.

Examples of similar ventilated roofs are found in Recife, Brazil, and Porto Novo, Benin, both former Portuguese colonies. In Recife, many buildings dating from the beginning of the twentieth century, particularly of the chalet type, have openings (normally circular) on the pediment of both the main and the back facades. The same devices are found at the Maison PREMA (Prevention in Museums in Africa), which was restored to its original configuration and currently houses the École du Patrimoine Africain.

Metal sheets for roofing are quite effective in warm, humid climates, for these materials can be at the same time reflective and impermeable. They are also highly conductive, and they cool down as quickly as they heat up. The traditional use of colonial ceramic tiles on roofs is also adopted because their juxtaposition normally allows for air leakage, and heat is permitted to dissipate through convection.

Thermal insulation for roofs is recommended in warm, humid climates because the sun in the sky is high. An insulation material 5–10 cm thick, with a low U-value of approximately 0.5W/m^2K, can be effective in reducing heat gains on the upper part of a building (Gut and Ackerknecht 2005). The use of materials with large thermal resistance, such as mineral wool, glass fiber, expanded clay, and cellulose, can reduce both heat gains and heat losses indoors and minimize daily temperature fluctuations (Baker and Lugano 1999).

Conclusion

The actual performance and efficacy of these building design features still need to be assessed systematically in warm, humid regions. There has been a lack of studies on passive museum buildings, as well as a lack of consistent gathering of climatic data. Random measurements, however, such as those taken at the Museu do Estado do Pará, have shown that its interior spaces are constantly warm, and this may be the reason that condensation never occurs. Its daytime users need a bit of air cooling and dehumidification, and to achieve that, an investigation into the use of nighttime ventilation in small amounts could be of help.

There has been an increasing demand for energy efficiency and sustainability in buildings, and museum buildings are no exception. This demand has led to new research and innovative projects on more passive ways of controlling indoor climate—not only for human comfort but also for the conservation of collections. The rejuvenation of a building's passive climate control features minimizes the need for mechanical aid, reduces energy consumption, lowers maintenance expenses, and makes the museum building more sustainable. But there is still an obstacle to the further pursuit of passive, low-tech solutions to climate control in museum buildings: these passive features may require users to look after and operate them—and this requirement may be difficult to achieve in practice.

Author Biography

Franciza Toledo, an architect who specializes in heritage conservation, has a PhD in museum studies. She was research associate at the Getty Conservation Institute and a consultant on museum matters to Fundação Vitae over the past six years. Recently, she was a fellow at the International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM), studying museum buildings in sub-Saharan Africa. As a private consultant, she has conducted investigations and has written articles on museum climate control in warm, humid regions.

Figures

Figure 1

The pavilion for computer and multimedia learning at the Museu do Marajó, Marajó Island, Pará, northern Brazil (built in the 1990s). The building is supported by stilts. Photo: Franciza Toledo.

a

b

Figures 2a and 2b
The storage building of the National Museum, in Abidjan, Ivory Cost, seen from the front (a) and from the side (b). The facility was designed by Gaël de Guichen to deal with a warm, humid climate passively. Photos: International Centre for the Study of the Preservation and Restoration of Cultural Property (ICCROM) Archives.

Figure 3

Houses with above-grade basements in Laguna (Lagoon), Santa Catarina, Brazil, a national heritage site listed by the Instituto do Patrimônio Histórico e Artístico Nacional (IPHAN), in 1985. Photo: Isabel Kanan.

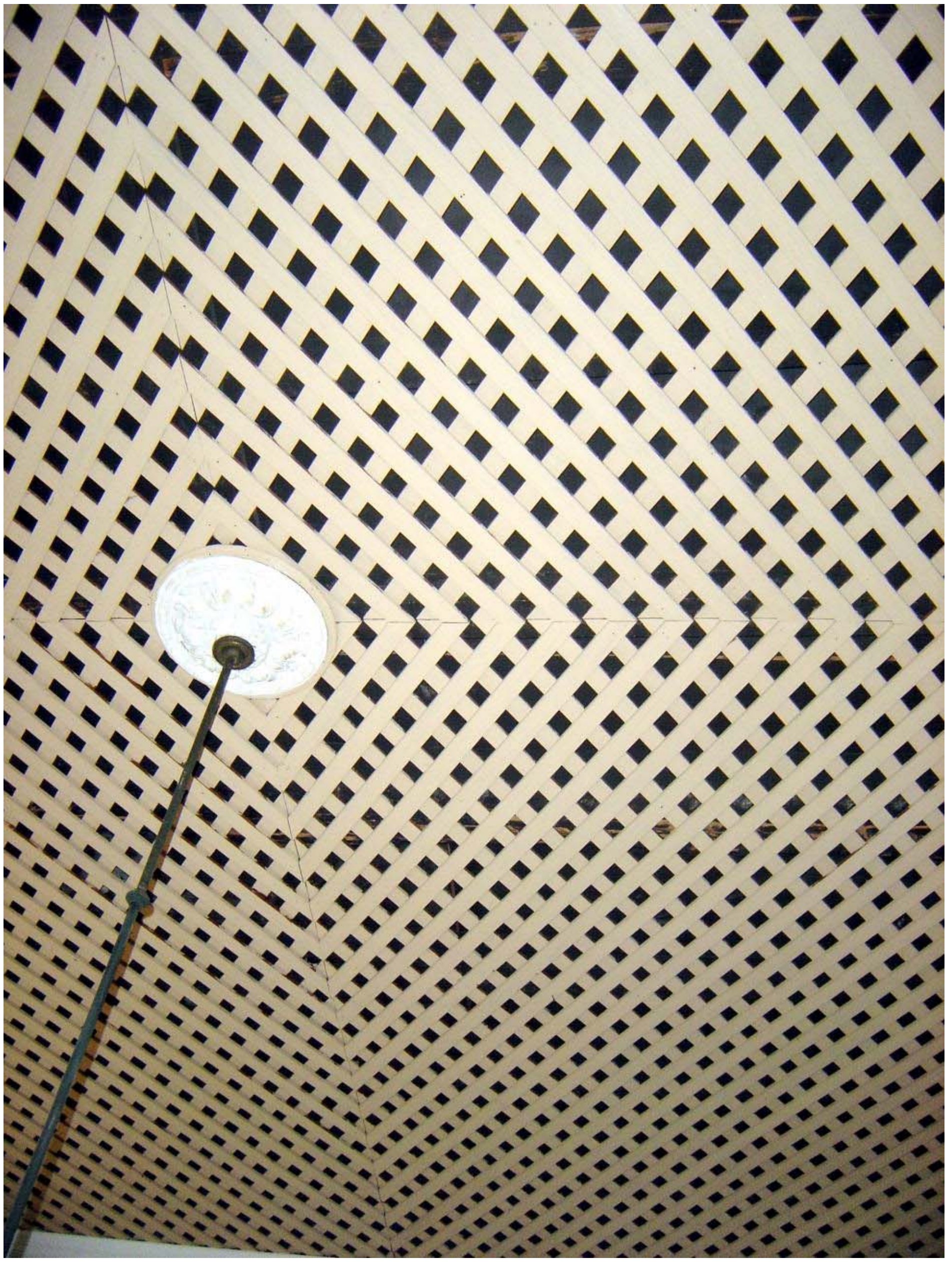
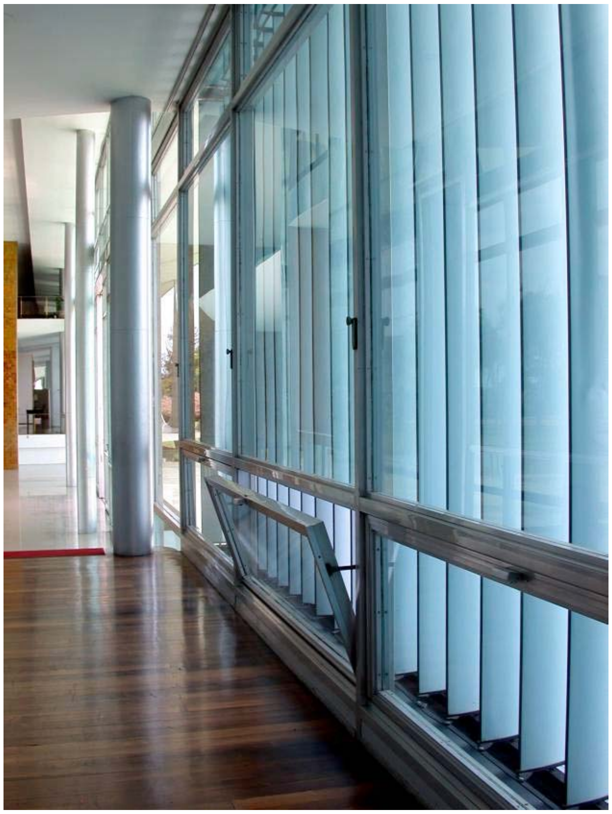


Figure 4

The trellised ceiling in the kitchen of the Casa de Rui Barbosa, Rio de Janeiro, Brazil. Photo: Franciza Toledo, with permission of the Fundação Casa de Rui Barbosa.

Figure 5

A private, listed building in the city of Recife, Pernambuco, northeast Brazil, with enameled tiles on its main facade and delicate two-layered windows and doors. Photo: Franciza Toledo.



a b

Figures 6a and 6b
The Palácio da Alvorada, Brasília, Brazil. An interior corridor along the main west façade (a) has movable glass panels and vertical *brise-soleils*; the exterior view (b) is of the back east facade. Photos: Franciza Toledo.

a

b

Figures 7a and 7b

The north balcony of the Casa de Rui Barbosa, Rio de Janeiro, Brazil, seen from the exterior (a) and the interior (b). The mural paintings are protected by awnings. Photos: Franciza Toledo, with permission of the Fundação Casa de Rui Barbosa.

Figure 8

The old Palácio dos Governadores, now the Museu do Estado do Pará, in Belém, Brazil. It is a massive building with a back loggia that led, in the past, to a large orchard (now completely supplanted by office buildings). Photo: Octávio da Silva Cardoso, with permission of the Sistema Integrado de Museus e Memoriais, Secretaria de Cultura do Pará (SIM/SECULT).

a

b

Figures 9a–c
A view of the roof of the Museu do Estado do Pará shows one of the two small remaining mansards facing the patio (a); a reproduction of a nineteenth-century photograph (ca. 1870) (b) shows that mansards also existed on the outer part of the roof (Crispino et al. 2006). Small raised vents on the edges of the chutes are a recent intervention (c). Photos: Griselda Klüppel.

c

References

Baker, Jennifer, and Fred Lugano. 1999. A passive approach to practical climate control. In *Postprints of the Wooden Artifacts Group (American Institute for Conservation of Historic and Artistic Works. Wooden Artifacts Group),* 34–45. Washington, DC: American Institute for Conservation of Historic and Artistic Works, Wooden Artifacts Group.

Camuffo, Dario, Emanuela Pagan, Adriana Bernardi, and Francesca Becherini. 2004. The impact of heating, lighting and people in re-using historical buildings: A case study. *Journal of Cultural Heritage* 5, no. 4: 409–16.

Crispino, Luís Carlos Bassalo, Vera Burlamaqui Bastos and Peter Mann de Toledo. 2006. *As Origens Do Museu Paraense Emílio Goeldi: Aspectos Históricos e Iconográficos (1860–1921).* Belém, Pará, Brasil: Paka-Tatu..

Daniel, Vinod, Steve King, Colin Pearson, and Ivan Cole. 2005. Stories from historic buildings. In *14th Triennial Meeting, The Hague, 12–16 September 2005: Preprints (ICOM Committee for Conservation)*, ed. Isabelle Verger, 625–31. London: James and James.

Daniel, Vinod, Colin Pearson, Ivan Cole, Wayne Ganther, and Steve King. 2000. Behaviour of museum buildings in tropical climates. In *Tradition and Innovation: Advances in Conservation: Contributions to the Melbourne Congress, 10–14 October 2000,* ed. Ashok Roy and Perry Smith, 45–50. London: International Institute for Conservation of Historic and Artistic Works.

Givoni, Baruch. 1994. Effectiveness of mass and night ventilation in lowering the indoor daytime temperatures. In *Architecture of the Extremes: Proceedings of the Eleventh International PLEA Conference, Dead Sea, Israel, July 3–8, 1994,* ed. Yair Etzion, 151–56. Sede-Boker, Israel: Published on behalf of International PLEA Organization by Desert Architecture Unit, Jacob Blaustein Institute for Desert Research, Ben-Gurion University of the Negev.

Gut, Paul and Dieter Ackerknecht. 2005. *Climate Responsive Building*. St. Gallen, Switzerland:

SKAT [Swiss Centre for Development Cooperation in Technology and Management].

Holmberg, J. G., and T. Burt. 2000. Preventive conservation methods for historic buildings: Improving the indoor climate by changes to the building envelope. In *Conservation Without Limits: IIC Nordic Group XV Congress, August 23–26, 2000, Helsinki, Finland*, ed. Riitta Koskivirta, 71–88. Loimaa: Loimaan Kirjapaino.

Monowar Jahan, S. A. M..1988. Hot and humid climate: A challenge for conservators. In *Control of Museum Climate in Asia and the Pacific Area: 18 September 1988: Kyoto, Japan*, ed. Nobuyuki Kamba and Sadatoshi Miura, 29–33. Kyoto: Japanese Organizing Committee of IIC Kyoto Congress.

Ke-Jian, Yuan. 1988. Short notice about the climate control of storage room. In *Control of Museum Climate in Asia and the Pacific Area: 18 September 1988: Kyoto, Japan*, ed. Nobuyuki Kamba and Sadatoshi Miura. Kyoto: Japanese Organizing Committee of IIC Kyoto Congress.

King, Steve, Vinod Daniel, and Colin Pearson. 2000. Air conditioning small tropical museums: A technical note. *AICCM Bulletin* 25: 33–36.

Maekawa, Shin, Claudia Carvalho, and Franciza Toledo. [2006] Um sistema para controle ambiental na biblioteca Rui Barbosa. Paper presented at "Preservação do Patrimônio Cultural: Gestão e Desenvolvimento Sustentável: Perspectivas: Anias do XII Congresso Nacional da ABRACOR: Fortaleza, Ceará, Brasil, 28 de Agosto a 1 de Setembro de 2006."

Maekawa, Shin, F. Toledo, and R. Arraes. [2006.] Um sistema de controle climático para a reserva técnica etnográfica do Museu Paraense Emílio Goeldi, Belém, Pará. Paper presented at "Preservação do Patrimônio Cultural: Gestão e Desenvolvimento Sustentável: Perspectivas: Anias do XII Congresso Nacional da ABRACOR: Fortaleza, Ceará, Brasil, 28 de Agosto a 1 de Setembro de 2006."

Padfield, Tim, and Poul Klenz Larsen. 2004. How to design museums with a naturally stable climate. *Studies in Conservation* 49, no. 2: 131–37. http://www.padfield.org/tim/cfys/musdes/musdes.pdf.

[Parl, Sharon C. 2004. Heating, Ventilating, and Cooling Historic buildings: Problems and Recommended Approaches. *The preservation of historic architecture – the US Government's official guidelines for preserving historic homes*. *The Department of Interior*. Guilford, Connecticut: The Lyons Press: 259-272.

Randl, Chad. 2005. *The Use of Awnings on Historic Buildings: Repair, Replacement, and New Design*. Preservation Briefs, vol. 44. Washington, DC: U.S. Dept. of the Interior, National Park Service, Heritage Preservation Services. http://www.cr.nps.gov/hps/tps/briefs/brief44.htm.

Reis Filho, Nestor Goulart. 2004. *Quadro da Arquitetura no Brasil*. 10th ed. São Paulo: Editôra Perspectiva.

Sangiorgi, Franco. 2004. Recovery and reuse of traditional rural buildings in Italy. In *First International Conference on Science and Technology in Archaeology and Conservation: August 12–17, 2002, Jordan: Actas,* ed. T. S. Akasheh, 401–11. Granada: Fundación el Legado Andalusí.

Taylor, Joel, Nigel Blades, May Cassar, and Ian Ridley. 2005. Reviewing past environments in a historic house library using building simulation. In *14th Triennial Meeting, The Hague, 12–16 September 2005: Preprints (ICOM Committee for Conservation): Control of Museum Climate in Asia and the Pacific Area,* ed. Isabelle Verger, Nobuyuki Kamba, and Sadatoshi Miura. London: James and James.

Toledo, Franciza. 1999. Passive Environmental Control for Museums in Hot-Humid Climates: Guidelines for Building Design and Fabric Improvements. PhD diss., University of London.

Ughenu, Vicent. 2000. Museums as a source of history. In *Museums and History in West Africa,* ed. Claude Daniel Ardouin and Emmanuel Arinze, 49–52. Oxford: James Currey.

Zhou, Baozhong. 1988. The measures of controlling the environment in museums. In *Control of Museum Climate in Asia and the Pacific Area: 18 September 1988: Kyoto*, *Japan*, ed. Nobuyuki Kamba and Sadatoshi Miura, 21–25. Kyoto: Japanese Organizing Committee of IIC Kyoto Congress.