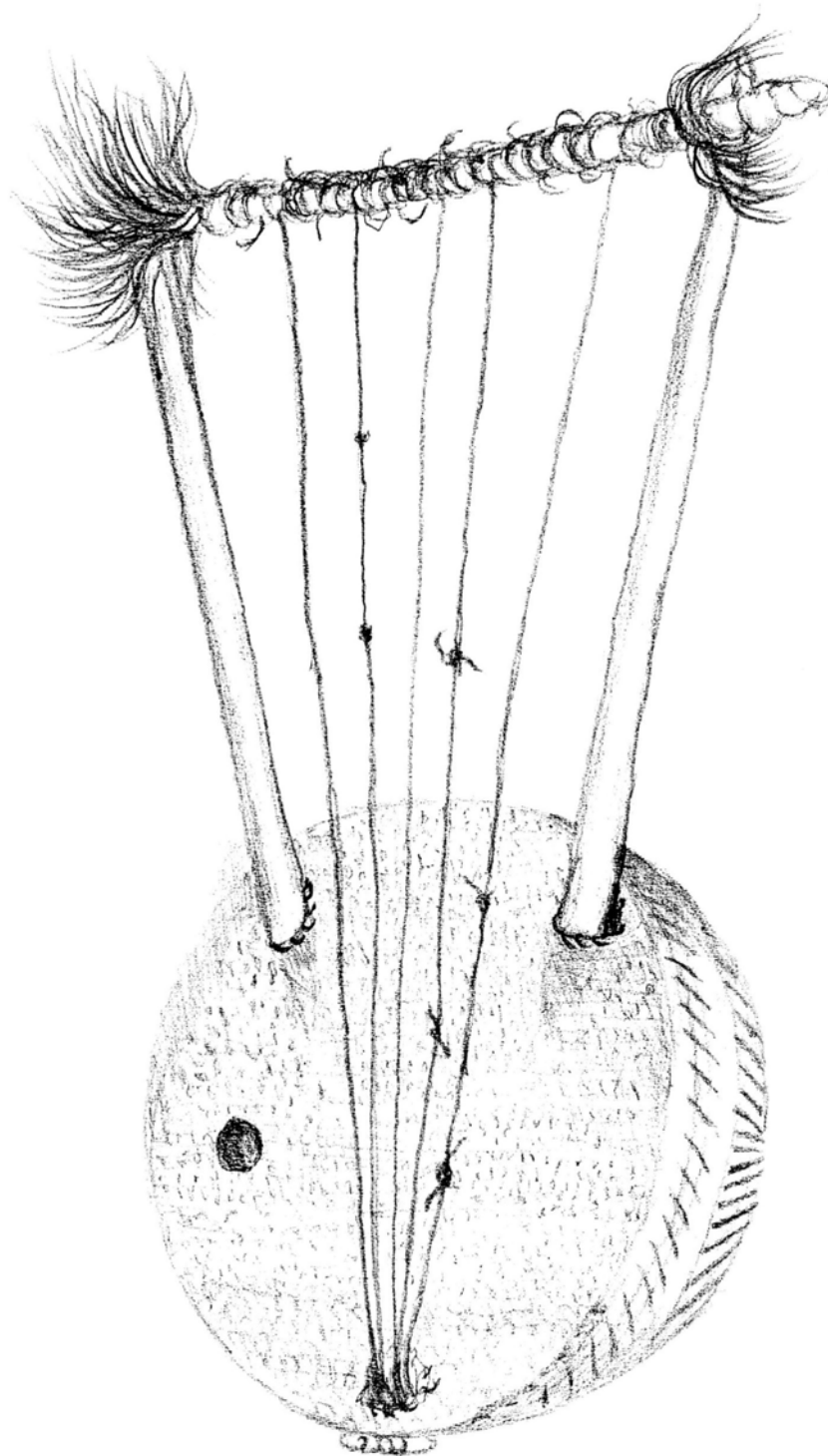


THE ROLE OF ARCHITECTURE IN PREVENTIVE CONSERVATION

Franciza Toledo

ICCROM research fellow

September to November 2006



Drawing of a musical instrument from the Livingstone Museum collection by Mr. Malace and Mr. Mizinga, during the 1991 PREMA – Prevention in Museums in Africa Course, in Zambia (ICCROM Archives).

Acknowledgements

This research was made possible thanks to the ever-present logistical support of Anna Stewart, the tireless attention and care of Paul Arenson, and fruitful discussions with Catherine Antomarchi, Gaël de Guichen and Zaki Aslan. Thanks are also due to all ICCROM staff, always cheerful and very kind, who make the institution a lively and exciting workplace.

Summary

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 materials. However, the architecture of buildings is commonly altered over time and through changes in use.

As time goes by, buildings acquire new uses and original spaces and architectural details are modified to suit new needs, thereby hindering the climatic performance of the building in its original state. In order to correct this, and instead of paying attention to the building's original design and use, architects and conservators tend to adopt and rely entirely upon mechanical HVAC systems as ideal climate control tools, for both human comfort and the conservation of museum collections.

However, many museums are housed in traditional, naturally ventilated buildings made with traditional materials and techniques, and it is likely that, merely by enhancing original architectural details or controlling the ventilation regime, climate control can be achieved for both visitors' comfort and material conservation, both of the building and the collection. Regardless of what is at stake, if museum buildings need some mechanical aid to control indoor climate, mainly due to urbanization and changes in their surroundings, it would be even more

efficient if the original building designs and spaces could be reviewed and rejuvenated.

Preventive conservation has so far overlooked original building design and construction materials and details as potential tools to control indoor climate in museums and archives. Few works have addressed this issue (Maekawa, Carvalho, and Toledo 2006, Padfield 2002, Toledo 1999, Christoffersen 1995, Cassar and Clarke, 1993, Tapol 1992). In Brazil, thanks to the Getty Conservation Institute and *Fundação Vitae Apoio à Educação, Cultura e Promoção Social*, new ways of approaching indoor climate control in museums have been developed. Some architectural improvements in the museum building, coupled with the use of certain mechanical aids (humidistat controlled ventilation and dehumidification), have been applied successfully.

This essay looks at the state of the art of the necessary and close relationship between architecture and preventive conservation, and how the International Centre for the Study of the Preservation and Restoration of Cultural Property – ICCROM has approached the architecture of museum buildings in its preventive conservation programs in Africa (PREMA), Asia (SPAFA), and Pacific Islands (PREMO and PIMA). ICCROM's methods of physical condition assessment, architectural evaluation, and types of enhancement made to both traditional and contemporary buildings that house museums in those countries, during these programs, are presented as they are documented at the ICCROM library and archives. This investigative study also highlights some aspects of museum building design and

fabric that may contribute to a better indoor environment for both collections and visitors in warm humid regions.

1. Literature review

There has been an increasing demand for energy efficiency and sustainability in buildings. Museum buildings are no exception. This demand in turn has led to new research and innovative projects on passive ways of controlling indoor climate, not only aiming at human comfort, but also at collection conservation.

Both old and new buildings may be capable of controlling climate passively. Old buildings used to respond to climate passively and had architectural features that once contributed to a good thermal performance (SMITH, 2004; MICHALSKI, 1998). Such constructions have physical and spatial qualities that should be evaluated, acknowledged and enhanced or rejuvenated. The rejuvenation of a building's old passive climate control features will minimize the need for mechanical aid, reduce energy consumption, make maintenance easier, and render the museum building more sustainable.

The climatic performance of a building is usually altered for two main reasons: changes in use and in surroundings. In order to comply with a new function, the building undergoes refurbishment, which commonly consists of removal or introduction of partitions, space modification, and blockage of circulation or openings. Similarly, the vicinity may be urbanized with new buildings and new roads, disturbing ventilation and sun paths and generating air pollution.

It is in the re-use or re-adaptation of existing buildings that the potential lies for a good conservation environment or a detrimental indoor climate condition. Attempts to upgrade old buildings to contemporary living standards, including safety, without damaging their structures or substantially altering their climatic performance is always a great challenge. The latter was the case at the *Marciana* Library, in Venice, where partitions were installed in large single reading rooms of the old building, in an effort to comply with new fire regulations. The building had previously been partially heated and displayed a good level of air mixture but, because of the new space segregation, over-heated areas were created that risked the preservation of the library's valuable book collection (BERNARDI, BOSSI and VILLANTI, 1999).

In many cases, the building shell is preserved, but its interior space is completely modified, and the architecture, in the sense of "enclosed space", is completely lost (AMORIM and LOUREIRO, 2006). Old buildings were recently rehabilitated in Egypt and, to fulfill the requirements of high-tech systems such as fire prevention, CCTV, elevators, air conditioning, etc., their interiors were altered to a greater or lesser extent. One cause is the lack of knowledge and skills on the part of some professionals involved, who approach such buildings as they would approach ordinary or new ones (GAMAL and SELIM, 2005). Two examples presented in the article are described as follows. A 19th century classical French style building was modernized to house the Egyptian Diplomatic Club and, for that purpose, the basement was occupied by machinery, original flooring was lifted so as to replace old ducts with new ones, cement-based mortar was used to consolidate the stone

masonry, and finally its interior decoration was redesigned after a French palace by an interior decorator. Another eclectic palace from the beginning of the 20th century was refurbished to house the Mohamed Mahmoud Khalil Museum and, for that, the storage area was placed in the basement together with the machinery, and its walls were chemically treated against water penetration. Basements, although usually inappropriate for this use due to their intrinsic coolness and dampness, are oftentimes converted into museum storage areas, and remedial actions such as making the walls impervious to water penetration simply conceals the problem and alters the original function of these transitional spaces. The authors concluded by stating that the rehabilitation of historic buildings in the Middle East has been a slow process of building modernization in all aspects.

New use requirements must be compatible with the spatial characteristics of an old building, or a great deal of refurbishment and stress on the building's fabric will result. Prior to intervention and occupation, if the evaluation of a building focuses only on its current physical problems and on remedial solutions, and does not consider its original configuration, spaces, layout or architectural details, the building's performance may change for the worse. It is necessary to understand the building's history and its original physical and spatial characteristics because they have contributed to its current state and may not be suitable for the new proposed use (McDONALD, 2004). Two questions should be asked first and foremost: how was the building primarily used, and what was modified throughout its lifetime that could be retrofitted or enhanced?

Past climates inside old buildings have been researched by the Centre for Sustainable Heritage, at the Bartlett School of Graduate Studies, in London, with the aid of archival documents, including architectural drawings, accounts and bills on past coal consumption and occupancy, and computer simulations, such as Energyplus®, Climate Notebook® and Time Weighted Preservation Index – TWPI®. A simulation of past heating regimes¹ in the library of Brodsworth Hall, in Yorkshire, a 19th century building owned by English Heritage, revealed that the best conservation environment for the books was the one provided by a combination of open fire and radiator. The study highlights, however, that the assessment of past environments is only possible because chemical deterioration calculations rely on average and not on fluctuation of temperature and RH values (TAYLOR et al., 2005).

An energy cost performance analysis was recently commissioned by British Gas to a consultancy firm in England, with the following results. Tudor houses leaked less and were warmer, and were therefore more energy efficient to heat than modern constructions. Victorian and Edwardian houses also did well in the tests, and the worst performance of all was given by the steel-framed buildings of the last fifteen years. The reason may lie in the construction speed adopted by building developers, resulting in cutting insulation materials in corners and missing sealing gaps in cladding systems (*Society of Antiquaries Newsletter*, cited by STANLEY-PRICE, 2006).

¹ Open fires (1863/1932), oil-fired boiler in the basement (1932/1945), a combination of radiators and open fires (1945/1990) and contemporary conservation heating (1990 onwards).

Computer simulation programs have been useful tools to evaluate thermal comfort and energy performance of historic buildings, both in their original and current conditions. ENER-WIN was used to assess three historic buildings: Saint Louis Catholic Church, in Castroville, Texas, USA, built in 1868 with thick limestone walls and covered with wooden shingles; the Unity Temple, in Oak Park, Illinois, USA, by Frank Lloyd Wright, built in 1905 with 'thoroughbred' reinforced concrete; and the Max Libling Bauhaus apartment building, by Dov Karmi, built in 1936 in Tel Aviv, Israel, a three-story building with deep horizontal balconies, made of silicate concrete blocks, stuccoed and whitewashed. When running the program with the original building architectural features, the results showed that their past energy annual outputs were better than the current recommended standards and that their design was environmentally conscious. Changes suffered by the buildings over time included, among others, sealing of openings, replacement of surrounding vegetation with pavement, and increasing numbers of occupants. The results also showed that simple measures such as weather-proofing windows and adding insulation to the roof would improve thermal comfort and reduce energy consumption of those buildings while maintaining their historic integrity (GEVA, 2005).

Both old and new buildings have been approached through the micro-climate they maintain, i. e. their climatic behavior. Not very often are their architectural features – design, inner space and fabric – correlated to such behavior. When a poor climatic performance, namely a problem of excess or lack of heat or humidity is detected, remedial actions are taken in order to improve the internal conditions, and commonly the intervention remains on the level of the fabric

(insulation or vapor barriers), or on its adjacency (correction or deviation of the source or cause of the heat or humidity problem). The relationship between a building's indoor climate stability and its thermal inertia, produced either by special building materials or thick walls, has been acknowledged to a lesser extent (DANIEL, 2005).

The building design (and the space it encloses) is seldom explored as a potential tool for a beneficial indoor environment. Space in its tridimensional aspects is seldom discussed when evaluating a building's climatic performance. The shape of rooms, ceiling heights, types and location of openings, roof forms, etc., which are so important to air movement and stratification, tend to be overlooked, yet all play a role in the conditioning of the indoor climate and should be placed into context when an environmental management plan is produced. The tridimensionality of a building is only taken into account when the air volume is a necessary value to calculate air renewal indoors and thus the capacity of mechanical climate control systems.

Changes in buildings can be classified in three types: intervention, when the building's design and fabric are modified; insertion, when the building's design and internal space is exploited to house a new smaller architectural element, such a shrine or a security vault; and installation, when accessory mechanical units or systems are attached to the building's fabric (STONE, 2005). The latter is the most commonly used type of building remodeling, since it is the easiest and least intrusive, and is oftentimes reversible. Depending on the type of climate, these systems can consist of forced ventilation, humidistatically controlled heating (or

dehumidification in the case of museum buildings in warm humid regions), moderate heating (in winter) or cooling (in summer), or full climate control (MICHALSKI, 1998).

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. Storage spaces dedicated exclusively to collections need minimum air renewal, just enough to dissipate gaseous pollutants generated by the collection materials themselves, and this applies to all types of climate. In cold or temperate climates, it is possible to rely entirely on a building's design and fabric for passive climate control. In warm humid regions, however, a combination of passive control (building design and fabric) and active control (air circulation and dehumidification) is necessary in storage spaces to prevent microbial deterioration. In exhibition spaces, where both encased collections and visitors are found, it is possible to adopt passive climate control when a building is designed to benefit from natural ventilation. If, on the other hand, the exhibition space presents an exposed collection, such as in a house museum where visitors can appreciate the contents in their original placement in the space, a hybrid control system is required, i. e. that provided by the building itself, as a better sealed protective envelope, coupled with forced and filtered ventilation, and often a bit of cooling (MAEKAWA, CARVALHO and TOLEDO, 2006).

It is even possible for museums to reach a common ground, with moderate climatic parameters, achievably satisfying the three types of physical requirements – those of building, collection, and visitor – in the aims of environmental control and

materials conservation (IZARD, 2000; ODDOS, 2000; MICHALSKI, 1998). Moderate climate standards, as a compromise between differing demands, can be achieved, given that psychrometrics show an area where human comfort and the conservation of most collection materials overlap, without stress to the building structure. In a few cases, depending on the type of collection or on the value of the building, the simultaneous fulfillment of the three demands may be impossible, and any attempt to satisfy one to the detriment of the others should not be considered (MICHALSKI, 1998).

Swedish engineers (HOLMBERG & BURT, 2000) performed a careful climate (particularly air infiltration) and architectural evaluation of three unheated multi-story palaces in Sweden and came up with passive and low-tech solutions to indoor climate improvement. The buildings had problems of high humidity and microbiological deterioration. Taking into account the buildings' architecture and original function, as well as the physical condition of the collections they housed, none or minimal intervention were seen as the best options. In the first building, which houses 30,000 well preserved books (mould growth was detected on calf skin book binders), the solution was to take advantage of leaky windows and infiltration of cold, dry winter air. The increase of air movement in the library rooms was produced passively, just by partially opening opposite internal doors and allowing for cross ventilation. In the second building, because of its very humid surroundings, a combination of passive and active methods of indoor climate control was achieved: the airtightness of the building envelope was improved by inserting removable inner windows, while a dehumidification system (with 4 desiccant units)

was installed in the attic. This system distributes dry air through a vertical line of chimneys on one side of the building while the used air is collected by a line of chimneys on the opposite side. At the third building, the cold and humid external walls of one of its two towers, covered with tapestries, were heated by a *Temperierung*, a system that consists of copper ducts embedded in the walls near the floor, filled with warm water. The walls are heated first, and afterwards the air next to it, mainly through radiation, with a reduction in moisture content of both the walls and the air in the room. The calculation of the ideal water temperature to produce the appropriate RH indoors was given by computer simulation².

Two successful research projects sponsored by the European Commission on passive solar heating, cooling and day-time lighting techniques and systems, JOULE III and SAVE II, generated proposals for passive design and fabric modification in six Mediterranean archaeological museum buildings, leading to performance enhancement and sustainability at these institutions (TAMBAZIS, VRATSANOS and PREUSS, 1999). Among other criteria, the museums were chosen because of their design representativeness and potential for intervention. In spite of the buildings being “old shells... with many problems of obsolescence”, they were strongly related to their adjacent environments, either as part of archaeological sites or as landmarks. The general retrofitting measures adopted were: small repairs and maintenance, thermal insulation and weatherproofing, functional ventilation strategies (nighttime ventilation or demand-dependent ventilation systems),

² Water at 50°C in the ducts generates a room temperature of 15°C. The water returns to the boiler at 30°C.

replacement of single-glazing with double-glazed windows, and installation of shading devices. Specific retrofitting measures were: new openings in internal partitions, new skylights and ceiling treatments, and new showcases, all aiming at incorporating continuous paths along visual axes and rearrangement of exhibits as part of the architecture and lighting design. The use of natural light was reinforced and improved, not only as an energy-saving measure, but also because natural light would not damage the collections, given that most of the archaeological materials were made of stone and not light-sensitive.

Historic listed buildings have limitations concerning design improvements, and normally interventions are restricted to their structure or fabric, aiming at strengthening decaying parts and/or recovering the physical properties of the building materials. In order to achieve passive indoor temperature control and conform to modern standards of human comfort, external thermal insulation coupled with internal vapor barriers have been heavily used in the recent past in historic buildings, although this has often meant sacrificing original fabric, as plaster, lath, masonry or finishes that could be partially or completely lost (PARK, 2004). A less drastic, reversible intervention in a historic building fabric, in an attempt to control its interior climate conditions, mainly low temperatures, was carried out at the Cornwall Congregational Church, in Cornwall, Vermont (BAKER and LUGANO, 1999). After studying the air movement within the building, the building was air-sealed and its air leakage was cut by 70%. After that, more than ten tons of cellulose paste was blown into the external wall cavities and attic. As a result, the electricity bill for space heating was cut by two-thirds and the community now uses the building year-round.

Controlling interior air temperature and relative humidity are more effective and less intrusive than installing insulation on the external walls of historic buildings. In a pioneering step, conservation heating was applied by the National Trust at its historic houses (BÜLOW, COLSTON and WATT, 2002; STANIFORTH, 1995). Heat is used just to lower relative humidity and not for human comfort, since the Trust houses are closed to public visitation during the winter. When heating is needed to improve interior climatic conditions, i. e. to avoid mould growth and/or metal corrosion, the humidistatically controlled panels are installed in hidden service areas and the heating apparatuses are discreetly inserted in the house museum rooms in order to blend in with the interior decoration and furniture. On various occasions, old systems already present in the houses, particularly ducting systems, were rejuvenated, thus preventing further damage to their fabric (STANIFORTH, 1995).

If they can be easily detached or retractable, external elements such as awnings can be added to the openings of historic buildings, to reduce sun incidence and indoor heat loads (RANDL, 2004). These devices, widely used in the United States of America, in the 19th 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 cooling costs inside both residential and commercial buildings. The US government, through its preservation programs, has encouraged the installation of awnings on both historic and non-historic buildings, partially financing such initiatives. As long as they comply with local municipality regulations, research in historic archives and old photographic collections helps in choosing the most suitable types of awnings, according to the shape, scale and location of doors

and windows. In North America, awnings can reduce 65% of heat gains when installed on south-facing windows and 77% on east-facing ones and, when used with air conditioners, they can reduce cooling costs by up to 25% (RANDL, 2004).

Not all museums are housed in listed buildings and, in those cases, there can be room for minimum changes in their design or fabric, with significant improvements to interior environments. Modern and contemporary buildings with architectural climatic qualities may be explored as protective shields for both collections and visitors and be references or pilot projects for indoor environment upgrade. Some were museum case studies in PREMA and will be discussed in the following sections.

New purposed buildings are supposed to respond more efficiently to users' needs. When the building is new and specifically built to house a museum, there is more flexibility and chance to succeed in its design and fabric. However, this has not been the case for new museum buildings designed by internationally famous architects. These buildings seem to become art pieces in themselves, conveying unusual shapes to urban landscapes, high technology and sophisticated building materials. Rather than creating passive conservation environments, many such buildings rely more and more on air conditioning systems to provide human comfort and stable environments for their exhibits, with an increase in energy consumption to compensate for the commonly famous lightness and openness of their construction. Glazed roof tops in particular, which have been recently installed over museum galleries and courtyards of some cultural institutions in temperate countries, have

caused more money to be spent in space cooling than in space heating (HOLBROOK, 2006; PADFIELD and LARSEN, 2004; CASANOVAS, 2003).

Buildings that can control exterior climatic conditions passively have been successfully designed for archives (PADFIELD and LARSEN, 2005; CABIROL, 2000; IZARD, 2000; PIZUTI, 2000; GIOVANNINI, 2000; BUCHMANN, 1998; CHRISTOFERSEN, 1995), libraries (CULLHED, 2005) and museum storage spaces (KNUDSEN and RASMUSSEN, 2005) in temperate and cold regions. Since they are places for documents, books or museum collections, air infiltration or renewal is kept to the minimum, just enough to dilute internally generated contaminants. In this way, exterior conditions have little effect on the building's interior. The building is designed to perform as a stanch box, with a selection of appropriate building materials that are thermally resistant on the outer shell and highly hygroscopic on the inner shell, thus acting as massive buffers. As a consequence, the interior climate hardly changes, and changes when they do occur are slow and seasonal. These buildings are famous for their very low operational costs.

The main reason that most examples of passive climate control design are found in temperate or cold climates is that it is easier to heat a building by passive means than to cool it. In such climates the architecture of buildings can be solid and compact. By contrast, in warm humid regions, cooling is achieved only if ventilation and shading are added to the design. Light structures and open shallow spaces are recommended in those regions, with the interior environment closely following the exterior conditions. Therefore, for museum purposes, cooling and simultaneously maintaining low RH levels indoors is difficult and currently achievable

only with some degree of mechanical aid. The use of nighttime ventilation to reduce temperature while maintaining RH daytime values inside buildings has not yet been systematically evaluated in warm humid regions.

Complete dependence on free-running buildings is still being adopted in many museum exhibition spaces in warm humid regions, where different climatic needs should be combined and conciliated: those of buildings, collections and visitors. However, the most challenging issue in such regions is using natural ventilation while at the same time avoiding insects and air pollution indoors. How to reconcile the need for openness and free air circulation for human comfort without allowing inside such detrimental factors for collections conservation? In small Asian museums, this task has been accomplished by carefully controlling natural ventilation and creating micro-climates for objects on view. The staff takes an active role in the operation of such buildings, i.e. 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 (ZONG, 1988; KE-JISAN, 1988; JAHAN, 1988).

Attempts to run air conditioning systems in such museums have failed (DANIEL et al. 2000; KING, DANIEL and PEARSON, 2000). In Australia over the past ten years, a project monitored conditions in some historic buildings, made of either brick or stone masonry, with and without mechanical climate control systems, including conservation heating. Data showed that when those systems fail, the resultant environment is more damaging than the natural conditions would have been: condensation and fungal outbreaks on surfaces are the most common risks (DANIEL

et al., 2000). In the case of a recent application of conservation heating, data registered climate variations that were larger than the natural ones (DANIEL et al., 2005).

Passive means of climate control may have their limitations, particularly in warm humid regions, but it is worth pursuing them to achieve sustainability. Since it is difficult to reduce high RH values passively, building users must play an active role, performing daily routine tasks in order to smooth or prevent extreme exterior conditions from coming inside. When and where a complete control of indoor climatic parameters is necessary, which is the case of chemically unstable archive materials, mechanical aid should be considered.

A mixed approach, using passive measures in combination with mechanical aids, was adopted at the new storage building for the ethnographic collection of the *Museu Paraense Emílio Goeldi*, in Belém, Pará, in the northern region of Brazil. The roof was insulated, the airtightness of the room was improved, and a mechanical climate control system using both ventilation and dehumidification was installed in 2003. Supply and exhaust fans placed outside the storage space operate when the exterior climate conditions are dry, while dehumidifiers and oscillating fans are activated when both exterior and interior climate conditions are humid. The system is controlled by two humidistats: the inside one controls the duration of the system's operation, and the outside one controls the operation mode. The cost of the whole system was one-fifth that of a typical air conditioning system. The system has operated successfully, maintaining the storage at 65-70% RH and 28-32°C (MAEKAWA, TOLEDO and ARRAES, 2006). The dust level in the storage was significantly

reduced. The system operates about four hours daily, mostly during the daytime, and the storage space currently expends one-fifth of the average energy use of the other air conditioned storage units. The system is robust and requires minimal maintenance: the humidity sensors require annual calibration and filters are replaced twice a year.

Another way to suit the triangle of buildings, collections and visitors climatic needs is to use forced and filtered ventilation, creating positive pressure inside the room and thus avoiding dust and insect penetration through gaps. A hybrid (passive/active) climate control system was recently installed in the library rooms of a house museum that once belonged to a prominent Brazilian, Rui Barbosa (MAEKAWA, CARVALHO and TOLEDO, 2006), in Rio de Janeiro. The book collection, the most precious item in the house, was threatened by heavily polluted surroundings and high humidity levels, particularly in summer. As the museum is housed in a listed building, the installation of a traditional air conditioning system would have damaged the original building fabric and was therefore unacceptable. An alternative way of providing a safe and stable environment was needed. In the 19th century, the building had dealt with harsh summers passively: its high ceilings had peripheral openings leading to an air-leaky roof, allowing hot air to be exhausted through gaps between the French ceramic tiles; cross ventilation was plentiful since the building has doors and windows on its four facades. Natural light was controlled by exterior Venetian blinds, internal glass panes and light curtains. An above-ground ventilated basement acted as an air cushion, separating the building from the humid soil.

The building suffered various changes throughout its life. In the 70s, many windows on the main façade were closed to reduce dust levels indoors. In the 80s the basement clearance was increased so it could be used for temporary museum activities: it received a new concrete slab floor, which pushed a high water table down; its walls were covered with a cement plaster; and an exhaust fan was installed in the space. In the 90s, because of increasing water infiltration³, the air-leaky roof was internally protected with an impervious membrane (Tyvek®), which hindered the natural exhausting of hot humid air through its structure. The alternative climate control system designed for the library considered and took advantage of all this. The electrical installation in the basement was reinforced to operate a more powerful ventilation system, which provides ducted fresh filtered dry air through diffusers strategically placed on the edges of the wooden floor in the rooms. The diffusers are located next to the bookcases, and follow the visitors' path. Forced ventilation is controlled by humidistats, inside and outside; the air is sucked out through the original narrow ceiling openings with the aid of an exhaust fan placed in the attic, whose duct discharges at a skylight on the house's main corridor. With the Tyvek®, the attic space above the library rooms became a large plenum. When outside conditions are detrimental, whether too hot (temperature above 28°C) or too humid (RH above 70%), the air within the rooms is re-circulated, through a return duct, after being dehumidified and slightly cooled to provide visitor comfort.

³ These water infiltrations were caused by weathering, dislocation or breakage of the French ceramic tiles.

Concerning material conservation, museum buildings have not been properly designed. It is easy to design a building without any sort of constraint and then to take care of climatic different requirements by installing an artificial system. The real challenge remains for architects and building engineers to design more climate responsive buildings.

2. Museum buildings in warm humid regions

In order to appraise the building's responsiveness to its surrounding environment, it is first necessary to gain knowledge of the local climate, particularly its annual profile, and compare it with what is measured and registered indoors. The conservation condition of its contents must also be evaluated, and correlations made. Sometimes it is better to do nothing. In this way it can be established that the building possesses an appropriate design and building materials and is correctly used to safeguard its contents.

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

For the sake of the museum building fabric, it is advisable to maintain interior conditions close to exterior ones. Architects should aim at minimum intervention, just enough to keep within limit values and prevent deterioration of materials. An indoor environment that slowly varies with the outdoor conditions is less harmful to the building fabric, which normally provides some climate tempering that may be

sufficient most of the time, while some mechanical services can be provided to moderate extreme climate conditions (PARK, 2004; HOLMBERG & BURT, 2000).

A high degree of climatic steadiness is a natural feature of warm humid climates. Daily and seasonal variations are low, and comfort is mainly achieved by shading and ventilating buildings. Precipitation is high throughout the year and wind velocity is generally low (GUT and ACKERKNECHT, 2005). Daytime temperature values vary from 20 to 32°C, while nighttime values range from 21 to 27°C. 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 warm humid regions, so the key issue is to use ventilation to reduce heat and moisture gains indoors. In the case of museums or historic buildings, this may mean slightly reducing interior human comfort levels, increasing climate control zones and cooling opportunities, and improving the energy efficiency of the building (PARK, 2004).

Similar climatic conditions allow for the use of the same building materials, shapes, volumes and techniques. These are closely connected, contributing to the definition of some common architectural types to be found in different places around the world (SANGIORGI, 2004). Buildings built in warm humid regions have physical similarities such as ventilated pitched roofs, long eaves, openings on all facades, above-grade basements and stilts separating the constructions from the humid ground, etc. These architectural strategies are present at the Museum of

Colonial History⁴, in Aba, Nigeria, built in 1903, at the *Museu do Marajó*, on Marajó Island, Pará, Brazil, and at the new storage building of the National Museum, in Abidjan, Ivory Coast, both built in the 90s. This storage, designed by Gaël de Guichen, is a simple correct way of dealing with warm humid climates passively, and will be discussed in detail in section three.

Examples of similar ventilated roofs are found in Recife, Brazil, and Porto Novo, Benin, both historic Portuguese cities (fig. 1 a/e). In Recife, many buildings dating from the beginning of the 20th century, particularly the “chalet” type, have a hole on the pediment of both main and back facades. The same devices are found at the *Maison PREMA*, which was restored to its original configuration and currently houses the *École du Patrimoine African* – EPA.



⁴ The building was originally the Old Consulate, a prefabricated construction made in England, and transported into parts to Nigeria, to become the headquarters of the Oil Rivers protectorate in 1903 (UGHENU, 2000). In 1985, it underwent renovation and was turned into a museum.



Figure 1: a) top – Museum of Colonial History, Aba, Nigeria, built in 1903 (source: *Museums & History in West Africa*) and b) the *Museu do Marajó*, Marajó Island, Pará ,Brazil, built in the 90s (photo: F. Toledo). Below – c) and d) historic buildings from the beginning of the 20th in Recife, Pernambuco, Brazil (photo: R. Lopes), and e) the *Maison PREMA*, which houses the *École du Patrimoine African* – EPA, in Porto Novo, Benin, (<http://www.epa-prema.net/>).

If air temperature and humidity are to be reduced indoors, some important architectural features should be highlighted. The placement of the building, with respect to the sun path, prevailing winds and driving rains, together with a good design and careful location of the openings, can lead to a better zoning and distribution of rooms according to their functions, and help creating a comfortable indoor space.

In warm humid regions, where torrential rains are frequent, drainage systems are important features in buildings. Pitched roofs are preferred, together with long deep eaves, external downspouts, and over-sized gutters. The rainwater should be quickly drained away from the building's surroundings and collected in a cistern located far from the building compound, as this water will be useful during the dry season.

Roofs can be ventilated (fig. 2 a/b). If the 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'. Metal sheets for roofing are quite effective in warm humid climates, for they can be at the same time reflective and

impermeable materials. They are also highly conductive and cool down as quickly as they heat up. New insulated metal sheets, of light colors, have been successfully used on buildings. The traditional use of colonial ceramic tiles on roofs is also recommended because their juxtaposition is normally air-leaky and allows heat to dissipate through convection.

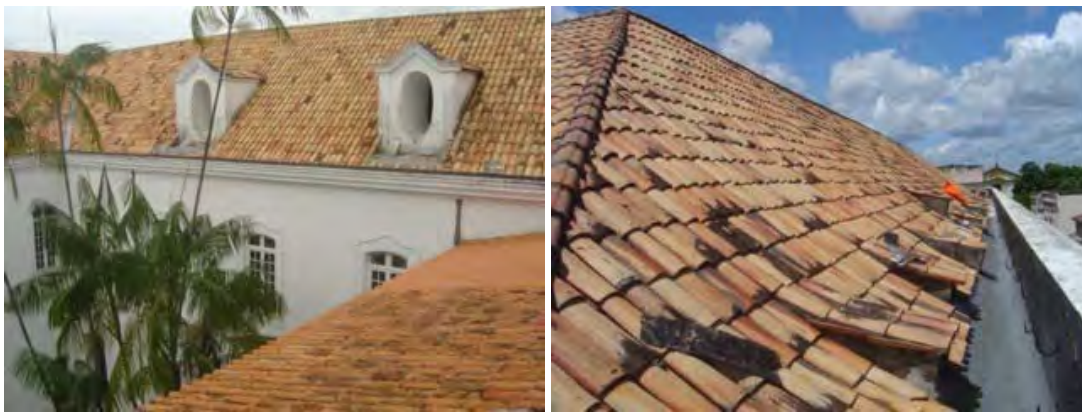


Figure 2: a) and b) example of a ventilated roof at the *Museu do Estado do Pará*, in Belém, that helps dissipate hot air. Source: *Sistema Integrado de Museus e Memoriais, Secretaria de Cultura do Pará – SIM/SECULT*.

Roof thermal insulation is recommended in warm humid climates, because the sun in the sky is high. A 5 to 10 cm thick layer of insulation material with a U-value of approximately $0.5\text{W/m}^2\text{K}$ can effectively reduce heat gains in the upper part of the building (GUT and ACKERKNECHT, 2005). The use of materials with high thermal resistance, such as mineral wool, glass fiber, expanded clay, or cellulose (BAKER and LUGANO, 1999) can reduce heat gains and losses indoors and minimize daily climate fluctuations.

The use of wall cavities (air cushions), thermal mass (thick walls) and external reflective materials, such as whitewash or enameled ceramic tiles, can help prevent

heat gains through external walls. Thermal mass or inertia is also important in providing a stable indoor environment since it promotes the stability of the interior air temperature. It helps maintain the building's interior coolness during the day, since the daily heat transfer is delayed for a couple of hours (GUT and ACKERKNECHT, 2005). In warm humid climates, however, coolness on the inner side of thick walls in the early morning hours may be a source of condensation, if warm humid air penetrates the building (GUT and ACKERKNECHT, 2005; DANIEL, 2005; DANIEL et al., 1999; TOLEDO, 1999).

The use of porous materials as interior finishes is also recommended in buildings to control air humidity. Wood cut against the grain, expanded clay and cellular concrete were tested in laboratory and shown to be efficient in controlling RH in archives, if the ratio of lined wall/ceiling area to room volume is about 0.7, and the air change per hour (ACH) is less than 1. A few centimeters of one of those absorbent materials would buffer daily climate variations, and together with a 40 cm thick wall would buffer annual climate variation if the ACH is kept at 0.1 (PADFIELD, 1999). At the Arnamagnæan archive of the Copenhagen University, Denmark, calcium silicate panels were recently applied as an interior finish of a concrete room, coupled with a certain amount of exterior thermal insulation and air intake. According to the authors, this approach is suitable for regions where summer temperature is below 25°C (PADFIELD and LARSEN, 2005).

Shading devices are quite efficient in reducing heat gains to the building's shell. The use of a sun path chart is the main criterion for the design of these devices. The efficiency of sun breakers, or *brise-soleils*, is principally due to their geometrical

shape and orientation (70%), and next to their material (15%) and color (15%). In general, shading elements should be vertical on east and west facades because the sun is low, and horizontal 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 by 10 to 20 cm to allow warm air to escape, and it is also important to reduce thermal bridging to a minimum. Shading materials should have low thermal capacity, i. e. the ability to cool down quickly after sunset (GUT and ACKERKNECHT, 2005).

Transitional spaces and *chemins de ronde* (GUICHEN, 2006) act as buffering zones and are always useful between conditioned and non-conditioned environments. Ventilated attics and above-grade basements, corridors, and vestibules are also useful as air-cushion areas. Many 19th century constructions have these architectural features. The principle of layered control to temper exterior conditions indoors can be applied in warm humid buildings, as long as stale air is prevented with some forced air recirculation.

The true efficacy of these building design features must still be systematically assessed, as there has been lack of study and consistent climatic data on passive museum buildings in warm humid regions. However, random measurements such as those taken at the *Museu do Estado do Pará* show that its interior spaces are warm but stable.

3. Museum buildings in PREMA

Problems faced by PREMA

At the end of the 1980s, ICCROM launched a preventive conservation training program in Africa because African museums needed attention (ANTOMARCHI, 1988). The Prevention in Museums in Africa or PREMA program, during its 10 years, had to face immense structural problems including lack of human and financial resources, and be extremely agile and resourceful in order to safeguard African museum collections from destruction, particularly from such ordinary events as insect infestation (PREMA reports). Some museum exhibitions were 10 years old and outdated. Both storage and exhibition rooms lacked proper furniture.

The majority of the African museum collections were found in storage areas, and PREMA training programs concentrated all efforts on physical improvements to these areas. In general, the storage reserves were packed with objects that were piled up, covered with dust, mouldy, and often heavily infested with insects. In addition, non-collection materials were deposited in the same space. This situation was due to three main factors: lack of trained museum staff, lack of periodical housekeeping, and uncontrolled interior environments. Most of the storage spaces were located in the most unfit rooms or zones of the museum complexes.

Some charts generated by a thermohygrograph in the storage of the National Museum of Ghana, in Accra, are available for analysis at the ICCROM Archives. From April to June 1989, the equipment registered high but quite stable climatic values. Temperatures varied from 27°C to 30°C, and RH values from 75% to 90%, the average being 80%. Despite the high values, the charts confirmed the steadiness of the storage's interior conditions, which is very important for the stability of the museum collection materials, particularly organic ones, and their consequent acclimatization to those warm humid conditions (GUICHEN, 2006).

During the lectures on climate and causes of damage, course leaders faced two recurrent indoor environment problems: high humidity and destructive insects. They acknowledged the need to cover control methods and agreed that these should be covered, but did not know what could be shortened to accommodate such a course session (PREMA 1st National/Sub-regional Course Final Report, Ghana, 1989).

Solutions given by PREMA

PREMA overcame many of the above problems and was a successful training program because it raised awareness in the world of the importance of the African museums, created a network of museum professionals to share information and experience, and trained trainers to multiply efforts for the preservation of movable heritage in Africa. It was a long-term and broad program that covered many complex issues concerning preventive conservation, ranging from museum

collection inventory and documentation to storage space evaluation and rearrangement. This latter subject is addressed below.

PREMA did not pay much attention to the passive features of museum buildings but successfully made African museum storage spaces functional. This was achieved not only by conserving and organizing the objects on covered and padded shelves, but also by changing storage environment and layout. Museum buildings were better secured and objects better protected, allowing for safer handling and circulation of the pieces within the rooms. Participants evaluated such spaces and proposed new layouts, shelves and fittings. The situation was visibly improved with the protection of the shelves against dust, with clear polyethylene sheets fixed with *velcro* and a regular cleaning of the premises. The collections were separated by type of constituent material, and the most sensitive ones were located in special segregated rooms or in more protected areas. A preventive conservation plan focusing on periodical surveys and maintenance resulted from each course.

As part of the training, the museum buildings were surveyed by the participants: one week of the course syllabus was dedicated to building condition assessment. PREMA participants were also familiarized with indoor climate issues: environmental aspects related to material deterioration such as high levels of temperature, relative humidity, light and air pollution, together with climate monitoring, were the subjects of one week of the course program.

In many storage rooms, natural ventilation was suppressed so as to avoid dust penetration, and ceiling fans were installed in the spaces to prevent stale air. Where natural ventilation was necessary and used inside the storages, microclimates were

created to protect the shelves. In other cases, openings were screened to prevent insects from entering. Climatic stability was further improved through a better sealing of gaps found in doors, windows and ceilings: these were either padded or caulked. Remedial measures to solve water leakage in roofs and rising damp on walls were also taken. Security measures such as the installation of burglar bars were applied in most of the museums studied. Unfortunately the new storage environments that resulted from PREMA interventions could not be monitored. It would have been useful to have climatic data before and after such spaces were modified.

Two storage units were designed with architectural passive features, but only one was built, in Abidjan. Its design will be discussed further below.

Museum buildings in PREMA

The museums studied by PREMA can be classified into four building categories that stem from: 1) old indigenous architecture; 2) old European architecture imported to Africa by the French or English colonizers; 3) international architecture built in Africa by foreign architects or local professionals who follow global trends, adopting high technology and new building materials while overlooking local environmental conditions or local traditional techniques and materials; and 4) temporary, poor constructions that lack sound structures and foundations. The analysis proposed here will take into account these four building types.

The indiscriminate use of imported building technology and industrialized building materials has threatened the existence of vernacular architecture, which

has been a living tradition in many African countries (ARADEON, KWAMI and TAXIL, 2005; ELOUNDOU, 2005). Old indigenous architecture can be found in Africa at mosques, palaces and dwellings, which are commonly made of mud and covered with thatch. These buildings are examples of an architecture that is climate responsive, given that earth, particularly if unbaked, is a good insulation material as well as highly hygroscopic. Such physical properties are very useful for regulating indoor climate. Nonetheless, these materials do not last long, requiring regular maintenance, and this may be a strong reason for locals to prefer to build using longer-lasting industrialized materials.

The palaces of Abomey, dating from the 17th to 19th centuries, are examples of indigenous constructions, consisting of a series of 12 small palace buildings built by successive kings of Dahomey. The buildings constitute a sort of architectural genealogy (AHONON, 2000). In 1985, they became a World Heritage site, while still serving as a place for royal ceremonies. King Glele's palace is a large rectangular building, 40m in length with rooms that open onto a verandah. It is known as 'Adjalala', meaning 'perforated from one side to the other'. Originally the openings had no shutters. The walls are made of red laterite. Clay trodden under foot was used to build the walls in blocks 50/60 cm high, made up of handfuls of mud stuck together. The walls are coated with kaolin and decorated with bas-reliefs. The roof structure was originally made of bamboo, teak or Iroko wood for the beams, and thatch for the covertures, with 4 slopes.

The building has undergone many changes and survived a fire. In the 1930s, the roofs were modified, and the thatch was replaced with corrugated metal sheets

that may have altered its original climatic performance, causing larger daily fluctuations. Now, the only way for the attic to be ventilated seems to be through the deep verandah. The interior is now protected by a wooden ceiling that might not have been there originally (fig. 3b), but may currently provide a more stable environment for the exhibits. Whether such physical and spatial changes have impacted the original indoor environment is unknown. No drainage system, such as surrounding water galleries, seems to have been installed (fig. 3a).



Figure 3: a) exterior and b) interior views of the *Musée Historique d'Abomey*. Source: ICCROM Golden Archive.

The National Museum in Conakry (fig. 4 a/b), Guinea, is also housed in a native building⁵. The problems faced by 1996 PREMA participants were, among others, the poor use of spaces, lack of storage space and adequate furniture, and a detrimental environment (both temperature and RH values were high: 35 to 40°C and 70%). The museum surroundings presented many risks to the collection: garbage accumulation; an open air sewage system that increased humidity and

⁵ U and L shaped buildings, always with courtyards.

attracted insects and rodents; an electrical transformer at the museum entrance, with uncovered wires, that could potentially cause a fire; and slums next to the museum buildings that could lead to robbery. The nighttime use of the museum's premises as a parking lot could also favor thefts, as well as an increase in dust and fire risk. As for the buildings themselves, museum access was easy and lacked security; the permanent exhibition space needed some upgrades, including security (installation of grills on ventilation openings) and a new layout.

Immediate proposed solutions were: 1) a transitional space around the museum of about 5 to 10m wide; 2) daily trash collection; 3) a drainage system for used water; 4) periodical dust removal in the museum premises; 5) night-lighting for the museum surroundings; 6) prohibition of night parking in the museum court; 7) care and maintenance of the electrical transformer (SOGEL); 8) closing the museum restroom doors after opening hours; 9) improving the electrical wiring of the museum; 10) time regulation for use of the bar next to the museum, as well as of the museum conference room. Proposed long-term solutions were: 1) providing signposts for the museum; 2) general cleaning of angles and openings; 3) filling in cracks and paint losses.

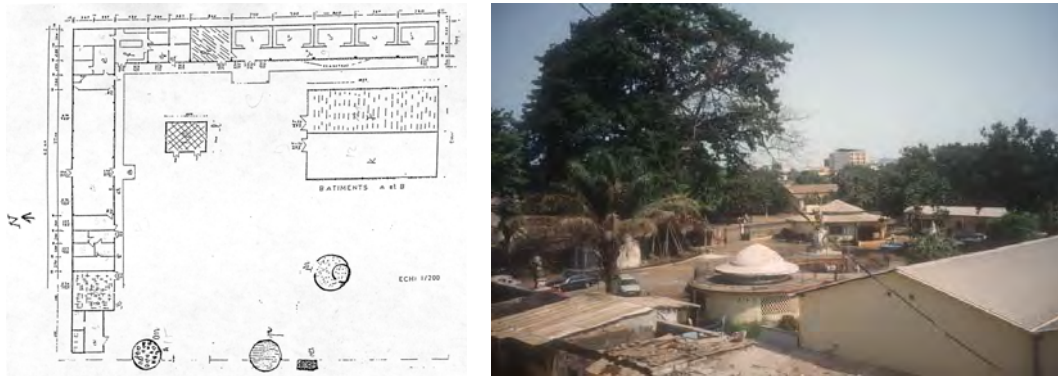


Figure 4: a) ground floor plan and b) south view of the museum complex. Source: ICCROM Archives.

The old European architecture that was brought to Africa by the colonizers is grandiose and stylish, but also presents design adaptations to the local climate, such as detached constructions with openings on the four facades, high pitched ventilated roofs, deep verandahs, above-grade basements, etc. They can be fortresses on the coast line, or palaces and institutional buildings further inland. Most of the buildings were built with massive walls that have weathered with time and are now damp, many of them showing water stains, contributing to increased moisture problems indoors.

The *Musée du Palais de La Reine* building complex in Antananarivo is an example of that old European architecture (fig. 5 a/b). Exceptionally, most of the buildings (90%) were made of hard wood. The collection was divided into three sites. An active insect infestation was found in two of the four towers at the *Palais Manjakamiadana*. Each tower had Venetian blinds for aeration. During the rainy season, water infiltrated through the roof and soaked the collection that was kept there. These conditions worsened with darkness and lack of climate control, leading

to a massive deterioration of the collection (presence of larva, insects, fungi, etc.). The relative humidity was constantly high at 75%, in spite of the natural hygroscopicity of the wood. Fungal proliferation was significant in poorly ventilated rooms. Gaps between wood planks forming the walls, along with malfunction of doors and windows which had warped over time, favored the intrusion of insects and rodents. Unfortunately, the museum complex was burnt shortly after the 1994 PREMA course. This misfortune reinforced the importance of risk assessment and management as part of the ICCROM's prevention conservation programs.



Figure 5: a) overall and b) detailed views of the *Musée Palais de la Reine* before the fire. Source: ICCROM Archives.

The Musée Grand Bassam is a typical colonial house (fig. 6). It is a two story building, with an above-grade basement, deep verandahs protecting the external walls from the sun on the two floors, and a four-slope metal roof that is ventilated on the two receded sides. The openings are framed by louvers, allowing for constant natural ventilation indoors. All these features contribute to smooth climate extremes and maintain a steady interior climate.



Figure 6: the *Musée Grand Bassam*, Ivory Coast, Africa. Source: ICCROM Archives.

The National Museum of Ghana (fig. 7 a/d) is an example of a modern, well maintained building from the early 1960s in the heart of Accra. It is clear that the design took the local climate into account. Glass bascules were installed on the upper part of the external walls and on vertical panes of strategic protrusions of the oval exhibition room, making the use of natural ventilation and light plentiful (fig. 8). Fixed louvers were installed on the lower part of the same walls. The purpose of such architectural features was to enhance natural ventilation and comfort indoors. Cooler air enters the rooms from the floor level, and hotter air is exhausted through the upper bascules. The downspouts are embedded in the external walls and, on the ground around the building, a slightly tilted peripheral cemented cradle appears to collect and direct rainwater away from the museum.

However, from the viewpoint of material conservation, natural ventilation and light could be rated as excessive. Direct sun incidence on a framed textile was photographed by PREMA participants, together with an attempt to diffuse it through

the installation of stretched cotton canvas on the inner part of the bascules. A more effective measure would have been installing a lightweight, reflective and, if necessary, detachable over-hang along the upper and outer perimeter of the museum buildings. This external shading device would have reduced the light levels indoors without hindering natural ventilation. In preparation for the 1989 PREMA course, nets were installed on the inner part of the storage openings, and security bars installed on the outer part of the upper bascules. As for the lower fixed louvers, they were sealed with plywood as they were the major source of dust indoors (ARDOUIN, 1989).



Figure 7: views of the National Museu of Ghana: a) PREMA participants conducting a condition assessment (upper left) and b) rearranging the storage room (upper right); c) and d) interior views of

the exhibition rooms, showing the upper horizontally and vertically displayed bascules, and the lower louvers. Source: ICCROM Archives.

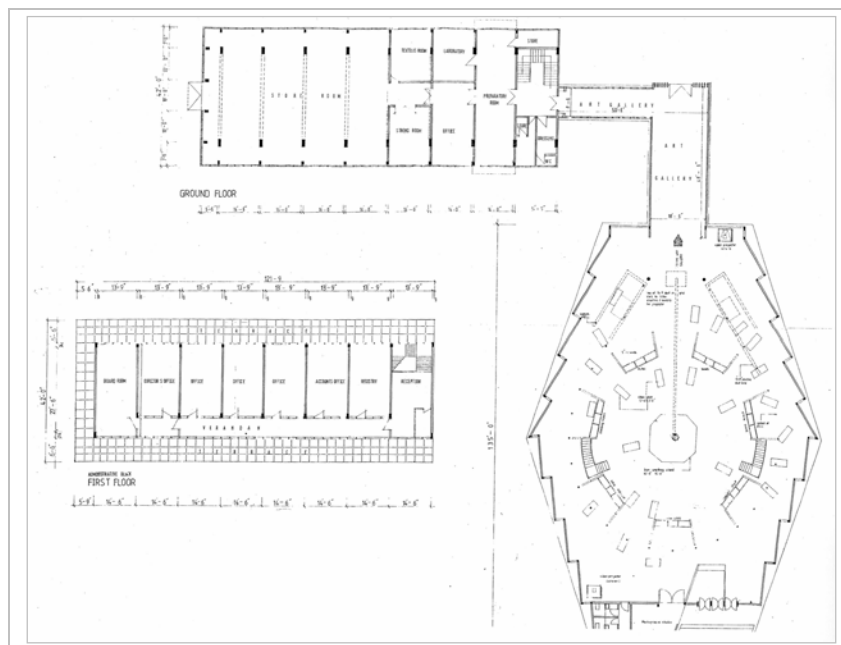


Figure 8: architectural plans of the Ghanaian museum complex. The large exhibition room on the right, the storage to the rear, and, on the first floor, the administrative area (lower left). Source: ICCROM Archives.

The Livingstone Museum dates from 1950 but it was enlarged and modernized between 1961 and 1965, with four different buildings and an area of 2,000 m² (fig. 9). It houses a highly varied collection of 48,517 objects and an ethnographic and art collection of 11,000 pieces. Only 2% of the collection is exhibited, and the rest is kept in storage.

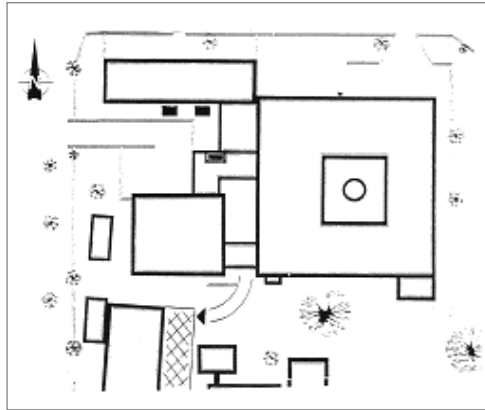


Figure 9: location of the national Museum of Livingstone, with the main building (with a courtyard) and its annexes. Source: PREMA 3rd National/Sub-regional Course Final Report. Zambia, 1991. ICCROM Library.

Contemporary museum architecture in Africa shows a clear rupture with traditional building techniques and materials. The *Musée d'Art et d'Ethnographie*, in Guinea Bissau, and the Museum of Human Sciences, in Harare, Zimbabwe, are two examples (fig. 10 a/d). They consist of concrete structures, walls in pre-fabricated cement blocks, glass panes on facades, and asbestos tiles on the roofs. Such building materials have detrimental effects on both visitor comfort and collections conservation, due to their heat capacity and heat accumulation inside the buildings.

Building materials have the ability either to reduce or store heat inside the building. Materials with heat storage capacity, such as concrete, should be avoided in warm humid climates, at least in rooms that are also used at night. On the other hand, a concrete building will be constantly hot and help maintain the RH constantly low. Such buildings are not suitable as museums, since visitors will be uncomfortable and chemically unstable collection materials will rapidly deteriorate.



Figure 10: a) the exterior and b) interior of the *Musée d'Art et d'Ethnographie*, Guinea-Bissau (above) and c) and d) the exterior of the Museum of Human Sciences, Harare, Zimbabwe. Source: ICCROM Archives.

The last type of museum building assessed by PREMA participants conveys a sort of temporary warehouse-type architecture, such as those found at the *Musée de la Gendarmerie de Madagascar* in Moramanga, and at the Railway Museum in Livingstone, Zambia. At the latter (fig. 11), according to the building's condition report, there were large gaps between the walls and roof, and the eaves did not extend out, letting dust and rain penetrate inside. Drainage systems were non-existent. The walls of the front gallery were made of asbestos and covered with wood. The main gallery had many open spaces and the air vents were too big, allowing various deterioration agents to enter.



Figure 11: general view of the Railway Museum in Livingstone, Zambia, showing the train station and its surrounding vegetation. Source: <http://www.mapasa.com/railway/railway.htm> .

The *Musée de la Gendarmerie de Madagascar*, in Moramanga, is also a ware-house type of building (fig. 12 a/b). One of the exhibition rooms was rejuvenated by 1994 PREMA participants. After the course, the museum planned to build a storage room for 2,000 objects in 1995.



Figure 12: a) the exterior and b) interior of the *Musée de la Gendarmerie*, in Moramanga, Madagascar, showing its lightweight coastal buildings and its surrounding vegetation. Source: <http://www.moramanga.kabissa.org/musee/historiquez.html> .

Museum storage spaces

The *Musée Historique d'Abomey* was studied by PREMA course participants in 1992. Created in 1944, it is housed in the two main palaces. It has a collection of 1,000 objects. The inventory dates from 1946 but has been updated by a conservator named in 1990. The old storage building was in poor condition and not safe (fig. 13 a/b). It was made with adobe bricks with 3 doors and 8 windows, separated into 3 rooms; the walls were disintegrating and the roof threatened to crumble; in addition, there was a general termite infestation; so the collection was moved out to a better storage space.

The new storage space, probably also in adobe bricks, now has only one outside door; and a second door leads to a room used for object preparation. The doors were provided with locks and metal bars and rubber gaskets on their lower part to prevent water and insects from entering. Openings and ceiling gaps were sealed. A space disinfestation was then conducted: the ceiling and the base of the surrounding walls were impregnated with *Proxonol*. Two ceiling fans were installed and the lighting system was modified, with 4 fluorescent light bulbs installed. A central pillar was built to support the wooden beams that seemed fragile. New furniture was provided and shelves were separated from the walls. The objects were disinfested and dusted before entering the new storage space.

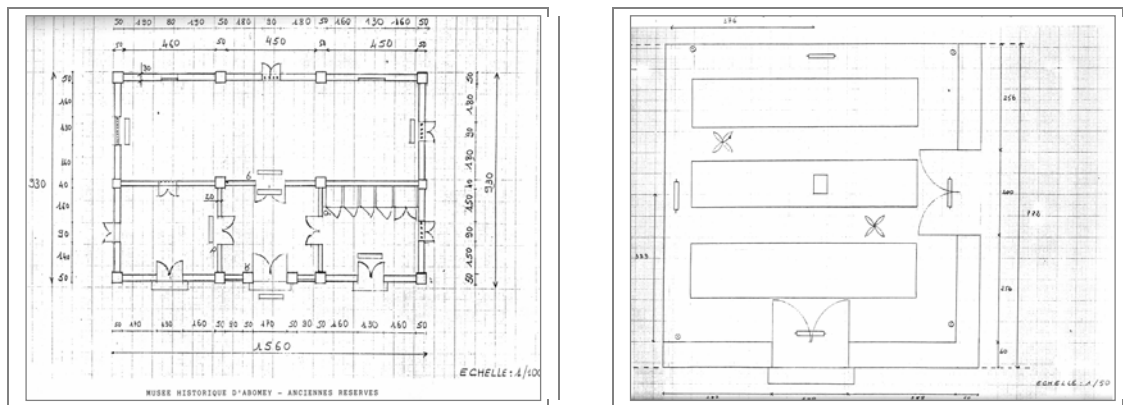


Figure 13: the *Musée Historique d'Abomey*, Benin; a) old (left) and b) new (right) storage rooms. Source: PREMA 4th National/Sub-regional Course Final Report. Benin, 1992.

Before-and-after architectural plans for the storage space of the *Musée de Ethnologie* of Porto Novo were drawn up when it was rearranged (fig. 14 a/b). The plans were schematic but very useful: the direction north is indicated; both areas and shelves are identified; area number 3 seems to be partitioned; there was an apparatus that could be a dehumidifier; and the location where termites were found was also marked. By comparing the two drawings, one can see that the layout changed considerably and the collection was stored according to type of materials. It is noticeable how circulation areas were cleared and circulation paths were defined by arrows. Concerning the building itself, it seems to be a detached, independent structure. The columns seem to be quite large when compared with the thickness of the walls, which could be a sign of an old, native building; there is also the projection of the beams crossing them. The storage space has two doors (north and west sides) and five small windows on the west façade. No description of the building materials or the type of roof is provided.

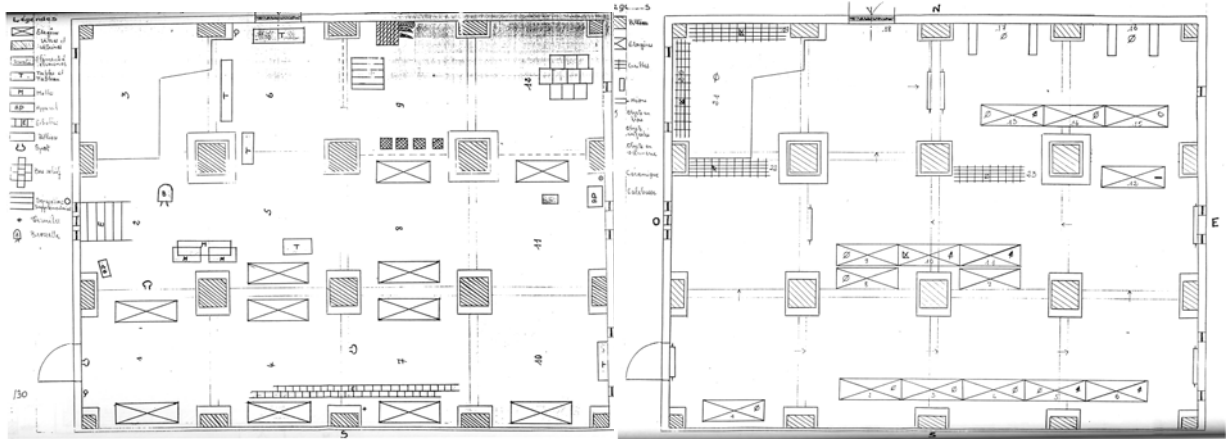


Figure 14: the *Musée d'Ethnologie*, Porto Novo, Benin; a) storage before and b) after improvement. Source: PREMA 4th National/Sub-regional Course Final Report. Benin, 1992.

After the 1994 PREMA course, in Madagascar, a new storage space was created on the first floor of the *Tranovola*, one of the wooden buildings of the *Musée Palais de la Reine* complex (fig.15). The conservation room was turned into the new storage space (139 m²). The main entrance was closed and the north entrance was reopened, with the creation of a quarantine room and an office for the storage facility manager, these being the changes in the building layout. As a result, 98% of the collection was gathered in this new space, all except for paintings. There were 1,100 objects, among them 388 textiles. 120 items needed to be moved to the new storage area. Soon afterwards, a fire at the museum complex destroyed all the work performed by PREMA staff and participants.

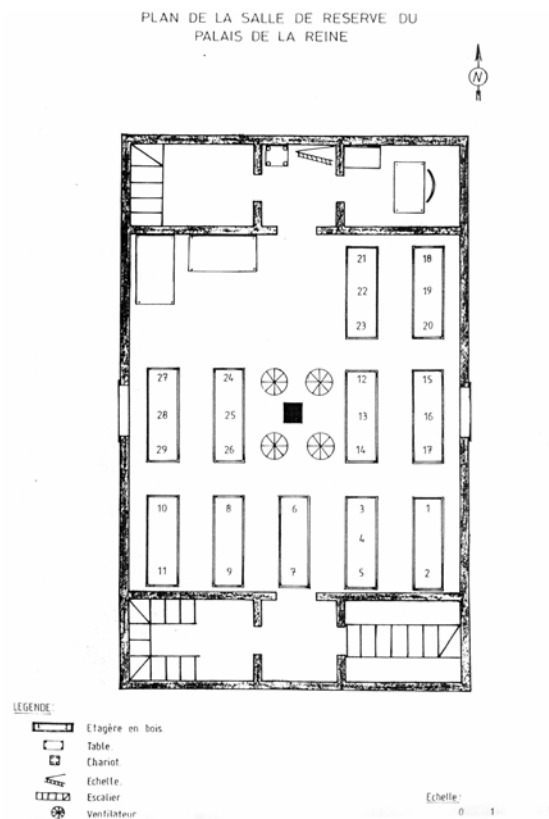


Figure 15: the storage space of the *Musée Palais de la Reine*, Atananarivo, Madagascar, after being rearranged by PREMA participants. Source: PREMA 5th National/Sub-regional Course Final Report, 1994.

The old storage space of the *Musée d'Art et d'Archeologie* was an underground room in the annex of the *l'Université d'Atananarivo*, in Faravohitra. The walls were in burnt brick and the structure in concrete (200 m²), with high openings on the north wall. It consisted of three offices and one quarantine room. The room was not built for collections; the walls had cracks where rainwater had penetrated, damaging the objects. The paving and the coatings were not waterproofed. The old restrooms had drainage problems and caused rising damp. The room was small for the size of the collection, which was damaged by frequent transfer, overcrowding, insect infestation, mishandling, and lack of furniture. Many objects stored in the area were not part of the collection. The museum had variable temperatures and a high

RH (85%). During the dry season, the objects were covered with dust that used to come with the winds.

The storage room was enlarged and renovated and, for that purpose, part of the courtyard had to be enclosed with masonry (fig. 16 a/c). The installation of a metal slide door allowed the entrance of large boxes. The old electrical installation was replaced, and three ventilators installed for a better air circulation. In addition, new supports were built, seven structures and two infested wood shelves were replaced, and two custom-made shelves and a structure for textiles were built. Doors were reinforced and an alarm system was installed. The space gained in the storage was also due to the transfer of the archaeological objects to another room that would be refurbished in 1995. The unnecessary material was disposed of, the infested objects were isolated and/or packed with polyethylene, and the collection was dusted before entering the new storage area.

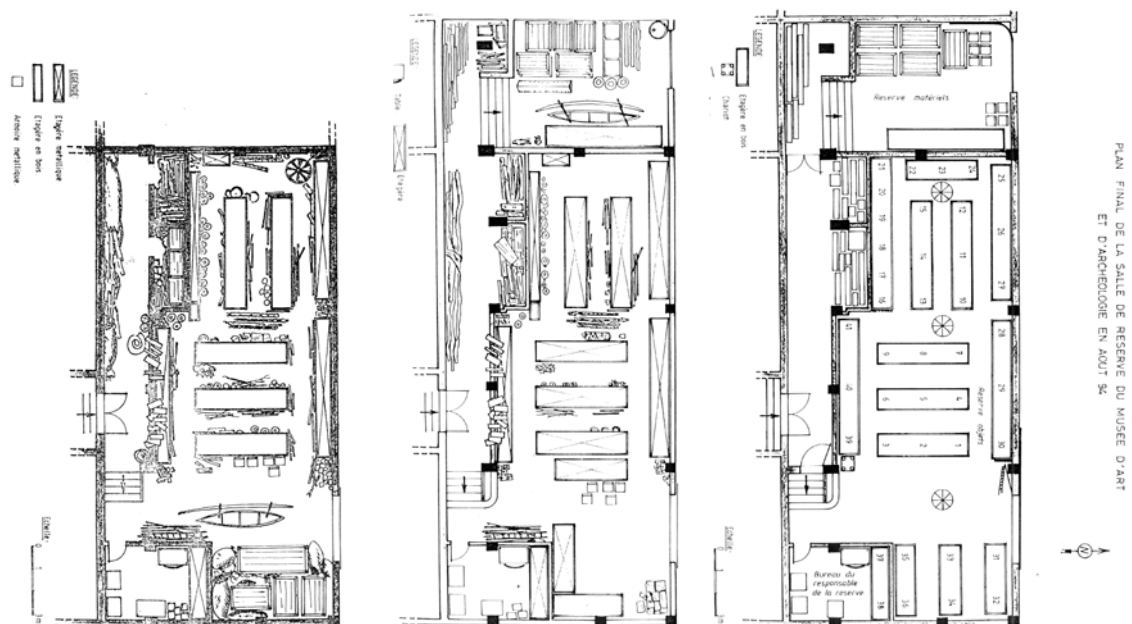


Figure 16: the three stages of the storage room of the *Musée d'Art et d'Archeologie*, Atananarivo, Madagascar – a) April (left), b) May (middle) and c) August (right). Source: PREMA 5th National/Sub-regional Course Final Report, 1994. ICCROM Library.

At the National Museum of Ghana, physical conditions were considerably improved in the storage area (fig. 17 a/c). The rectangular space was full of objects placed on the floor and had underutilized areas. The final layout shows a tidy space with the collection separated by different constituent materials: paintings and textiles were placed in segregated rooms at the entrance of the storage, while the rest of the ethnographic collection was kept in the main room in two rows alongside a central corridor. Shelves were detached from the external walls, not only creating circulation areas along the side external walls (*chemins de ronde*), but also freeing original fixed lower louvers and upper bascules, and enabling the originally designed aeration devices to be retrofitted. The sealing of the louvers was recommended in

12.85M

19.60M

KEY

SC. Show-case
St. Statue
MS. Metal shelf
WS. Wooden shelf
CW. Cabinet, wood
MC. Metal cabinet
W. Wooden rack
P. Paintings
R. Rack
xxx Objects on floor

STORAGE ROOM (April 1989)

Scale 1:100, Drawing by F.Zink

N^o 1



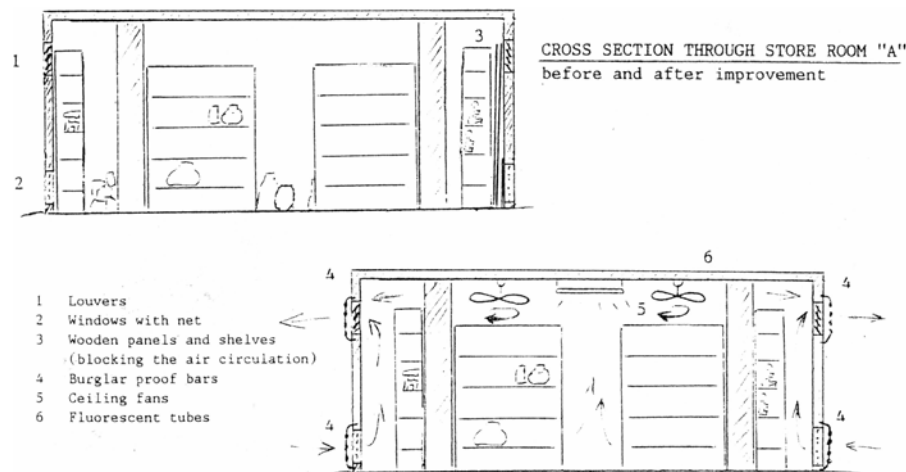
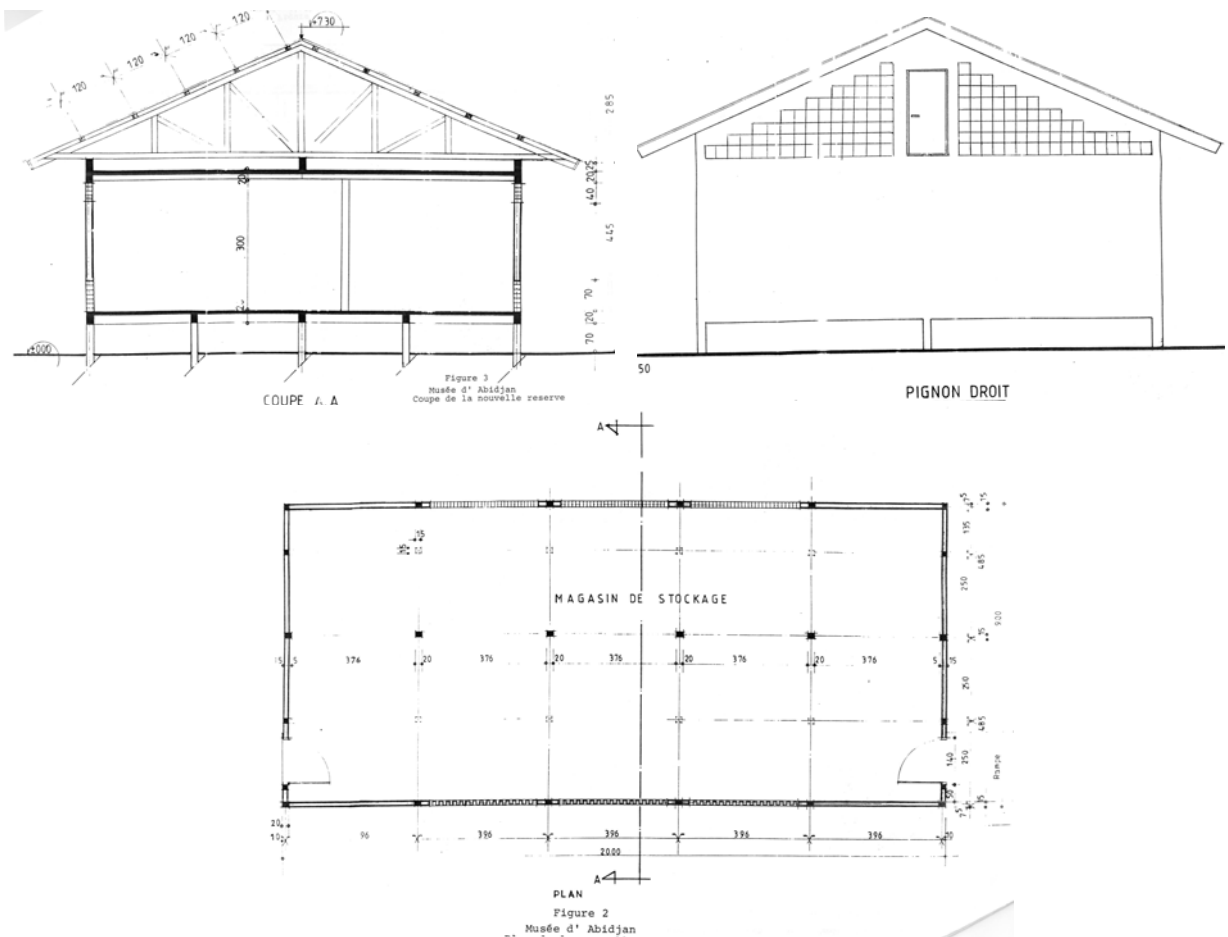


Figure 17: a) and b) plans and c) cross-sections of the storage of the National Museum, in Ghana, before and after rearrangement. Source: PREMA 1st National/Sub-regional Course Final Report, 1989.

The new storage unit of the National Museum in Abidjan, Ivory Coast, was designed by Gaël de Guichen to deal passively with the warm humid climate (fig. 18 a/c). The trainers contributed to the construction of the building with written specifications. The building is rectangular, measuring 20 x 09 x 03 m, and raised on stilts 70 cm from the ground, with a ventilated (trellised) and accessible attic space. Its light-colored metal roof, over wooden trusses, has long eaves to avoid rainwater on the walls. The two metal doors are accessed by large ramps for carts. Upper and lower narrow trellises, along the longitudinal walls, are provided with galvanized steel mosquito nets (1 mm). Air circulation is assured by 5 evenly distributed fans. There are 3 electrical mains on each side. *Gerflex*, a resistant material, was applied on the floor. The new storage unit is located between the exhibition pavilion, a rectangular symmetrical building facing the street, and the administrative U-shaped building at the back of the terrain (fig. 19). It was constructed in four months and its climatic performance is still to be assessed (GUICHEN, 2006).



Figure 18: the National Museum, Abidjan, Ivory Coast; a) side and b) front view of the new storage building designed by Gaël de Guichen. Built on stilts, it has screened openings (upper and lower) on its four facades, allowing for plenty of cross ventilation. Below c) drawings of the storage - plan, cross-section, and elevation. Source: ICCROM Archives.



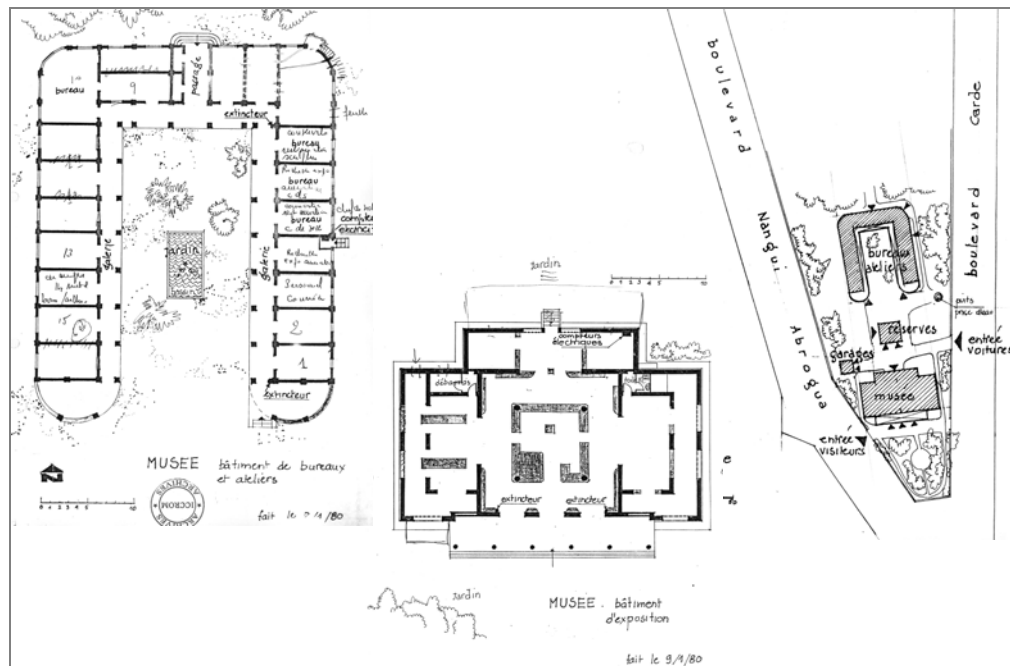


Figure 19: the National Museum, Abidjan, Ivory Coast. General plan, with the exhibition building in front (rectangular and simetrical), the administrative building (U shaped) on the left, and the location of the storage building (both old and new one) in the middle of the two. Source: ICCROM Archives.

The Livingstone Museum's storage B unit was not a suitable space, given that its northwest wall had $\frac{3}{4}$ of its area underground, in the basement of the museum building. The gutters were too shallow. It had many openings (doors and uncontrolled vents), exposed wiring for an air conditioning unit and a water pipe running through the room. Therefore, one of the objectives of the 1991 PREMA course was to transfer storage B from the basement to a new storage space. For that, a temporary exhibition room was turned into a storage room (120 m²). The plan had been to fundraise and build a new storage building, but this was ultimately not possible (fig. 20 a/b). Before transfer, objects were cleaned and some were disinfested through deep freezing. Further improvements proposed by the participants were to install curtains on windows, to seal doors (except the main one)

and gaps, to equip fluorescent lights in hallways with UV filters, and to provide the storage space with a torch, a ladder, and two fire extinguishers (inside and out).

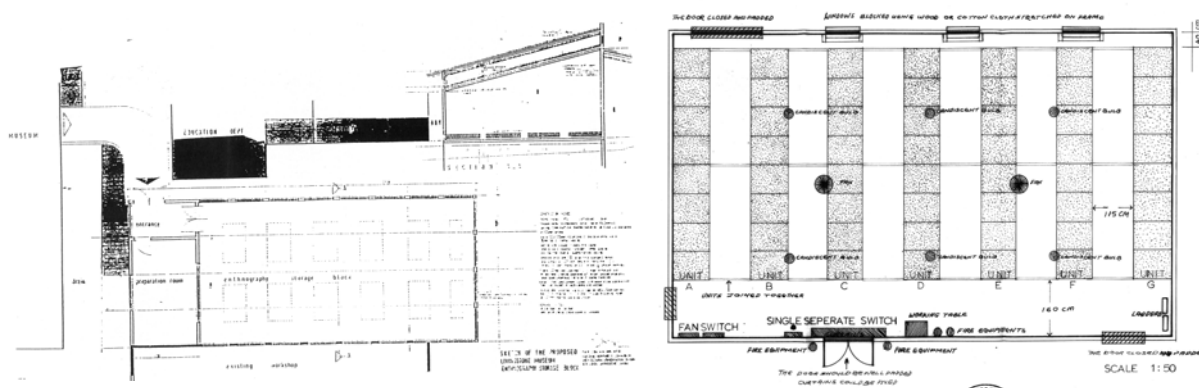


Figure 20: a) storage proposed for the ethnographic collection of the Livingstone Museum, Zambia and b) a former exhibition room that was turned into the new storage space. Source: PREMA 3rd National/Sub-regional Course Final Report, Zambia, 1991, and ICCROM Archives.

While still in Zambia, the course participants visited the underground storage space of the Nayuma Museum, in Limulunga. Bob Barclay and Friedrich Zink, the course leaders, produced an interesting report on the building. The aim of the visit was to anticipate how the storage could be upgraded. There was no building construction history or written documentation available. Temperatures of 28°C were registered at the end of the dry season. There were a humidifier and a dehumidifier, with separate humidistats (out of calibration), which sometimes operated simultaneously. Two ceiling fans were turned off (one was broken). The storage space was sealed by two doors, located at the top and bottom of the staircase, yet two vents on opposite sides of the storage space could still bring dust and insects inside. For a passive approach, relying on the temperature stability of the ground, a sealed storage space would have performed better. Immediate recommendations were to close the vents, seal the doors, install automatic door closers and horizontally

oriented fans in the dead space of the staircase, and replace the fluorescent lights with tungsten ones. The course leaders also suggested installing air circulation/RH control fan machinery under the central staircase.

The Museum of Human Sciences, in Harare, Zimbabwe, had a few problems, including inadequate storage, space misuse, unstable/uncontrolled environments, and lack of dust control. There were two storage areas (Zimbabwe and Africa) set apart; in between there was the committee room, with lots of space taken up by passages. The new proposed storage area combined the two old ones and reduced the passage area. Shelves were heightened (4.17m), space was created for large objects, a wooden door was replaced by a brick wall, thereby maximizing security and climatic stability, shelves were covered with polyethylene to minimize dust, more office space was created, and a water pipe was re-routed (fig. 21 a/b).

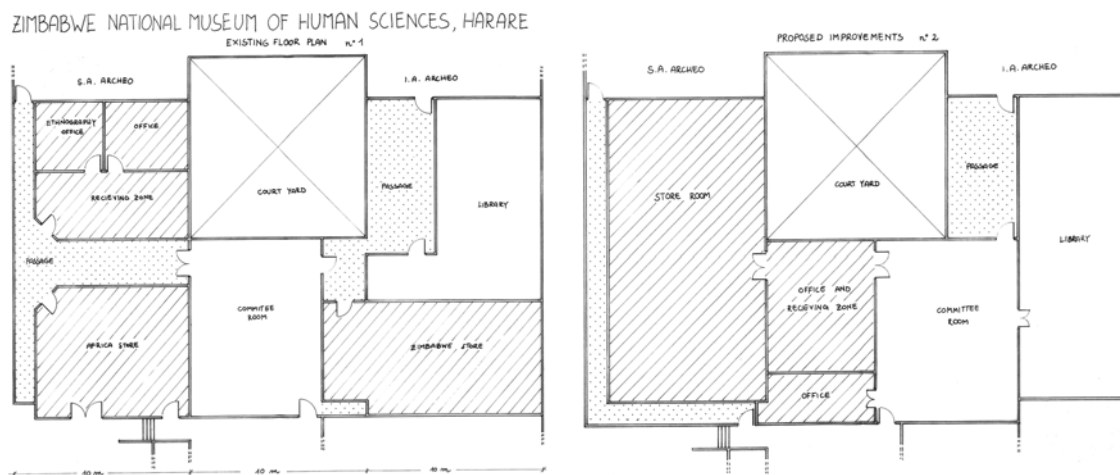


Figure 21: the Museum of Human Sciences, in Harare, Zimbabwe, storages spaces: a) before (left) and b) after (right) improvement, with a more rational use of space and circulation areas. Source: ICCROM Archives.

At the National Museum in Conakry, 1996 PREMA participants conducted a general inspection of the museum buildings, collections and environments, fumigated infested objects, and rearranged the storage space, among other museum practices. In the storage space, the ethnographic collection was covered with dust, mainly caused by car movement in the museum courtyard. The storage spaces were overcrowded, and this situation favored deformation, abrasion, and falling of objects; the piling up of textiles favored mould growth; wooden objects were eaten by termites; and metal objects were corroded due to high humidity and dust. The roof of storage 1 had water infiltration; leaky windows allowed dust, insects and light to penetrate both storages 1 and 2. More space was allocated for a new storage, next to the museum stands, but the space needed improvement since its walls presented water stains on the lower parts, the external double wall had fissures, its floor was not level and also showed water stains, and the vents did not adequately provide for ventilation needs and were not protected, letting insects in (fig. 22 a/c).

The actions suggested by the participants to improve the conditions in the storage rooms were: a) investigating the cause/source of rising damp in the new storage area; b) sealing the gaps between ceiling and walls in the storage areas; c) inclining the sidewalks around the new storage space to allow rainwater out of the building; d) roof maintenance over storage 1; e) installing gutters and downspouts to drain rainwater into the public water galleries; f) sealing doors and windows; g) leveling the floor of the new storage area; h) applying another layer of cement to

the floor of storages 1 and 2; i) repairing air conditioners; j) using fans; and k) recharging fire extinguishers.

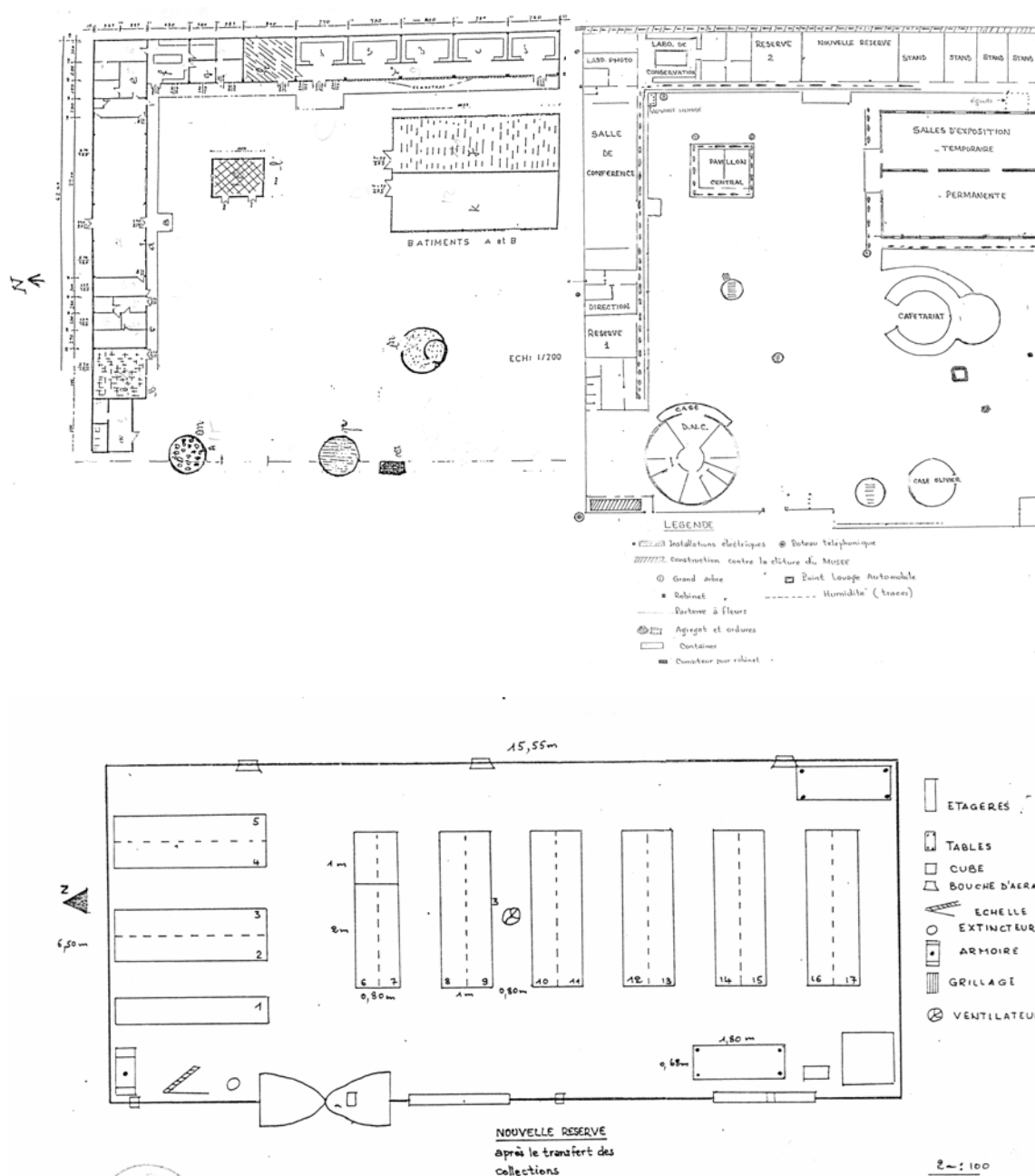
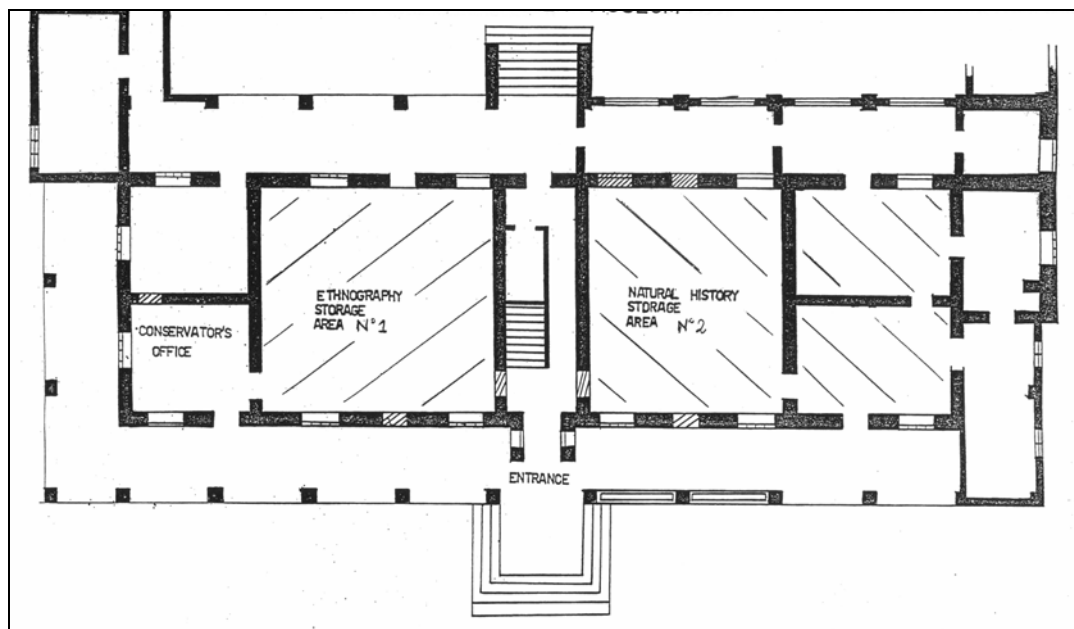


Figure 22: the National Museum, in Conakry, Guinea; storages spaces a) before (above left) and b) after (above right) improvement; c) detailed drawing plan of the new storage room. Source: PREMA 7th National/Sub-regional Course Final Report, Guinea, 1996, and ICCROM Archives.

The main problems found in the storage area of the Museum of Malawi's Top Mandala, in Blantyre, were mixed collections in the same space and permanent and temporary exhibitions, respectively 22 and 10 years old, in need of improvement. Two separated storage spaces were created, for natural history and ethnographic objects (fig. 23 a/c). Both storages, on the ground floor, were provided with ceiling fans. Faulty water works on the upper floor were repaired. Iron bars were placed on windows and doors. Weeks 13 to 16 of the course were spent on the storage upgrade. For this, shelves had been constructed prior to the start of the course, so that padding and dust proofing of all shelves, installation of burglar bars (XXX on the drawings), space arrangements and circulation paths could be carried out during the course.



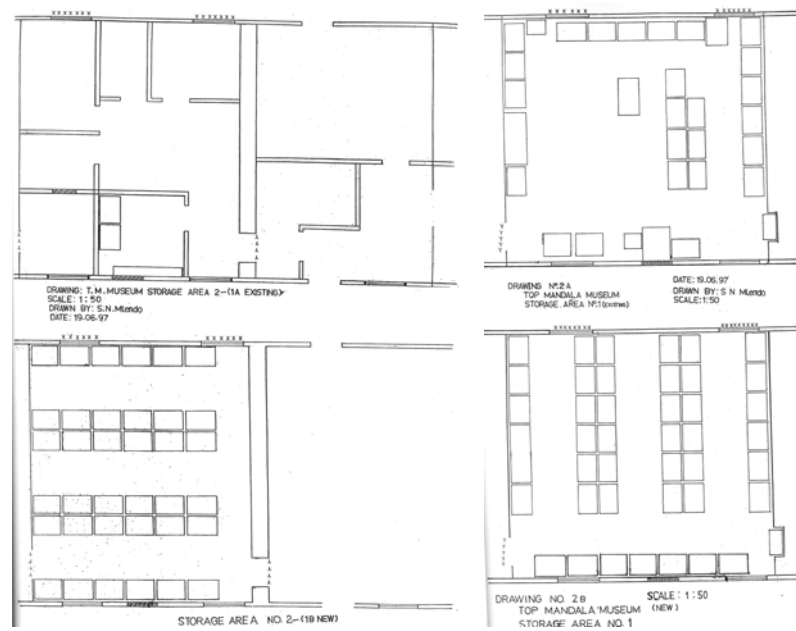


Figure 23: the Top Mandala Museum, Malawi; a) general plan and b) the two storage spaces before and after spatial organization. Source: PREMA 8th National/Sub-regional Course Final Report. Malawi, 1997/98. ICCROM Library.

4. Conclusion

Literature review on the subject, along with a analysis of PREMA documentation, showed that architectural evaluation of museums and historic buildings has typically taken a remedial approach rather than a preventive one. Museum buildings were assessed by professionals because their decay processes presented problems either for the collections they housed or to visitors. In so doing, the possibility of rescuing or rejuvenating past indoor environments or passive building features, or even inserting new elements that could enhance their climate performance, has commonly been disregarded. Yet understanding a building as a system, and how it was primarily used, can lead to minimum intervention, energy savings and sustainability.

Environmental qualities of both old and new buildings have recently been highlighted with the aid of computer simulations, as a result of energy performance evaluations of several buildings of different ages. Computer simulation programs to evaluate buildings' performance, despite their commonly criticized lack of exactness, can produce scenarios leading to the best possible solution for interventions and improvements in museum buildings.

The adoption of passive building design to create conservation environments has been increasingly developed and applied in archives and museum storage spaces in both temperate and cold climates. On the other hand, museums

exhibition spaces continue to rely to a greater or lesser extent on HVAC systems. Modern museum buildings are testimonies to high technology, heavily depending on high energy and maintenance costs. The opposite has happened in warm humid regions. Passive architecture, particularly of the type benefitting from natural ventilation, has been created for museum exhibition spaces. However, it can be detrimental to collections, bringing light, pollution and instability inside. If ventilation is reduced to stabilize the building's interior, it can be very difficult to reduce heat and moisture loads inside the building envelope. The use of controlled nighttime ventilation, coupled with building thermal inertia and highly absorbent finishing materials, has not yet been systematically investigated in storage spaces in warm humid tropics.

Another gap in literature concerns few information, research and case studies on passive design for museum buildings in warm humid regions of the globe. Aside from some studies carried out in Australia, consistent references cannot be found on Asian or Latin American museums. These will be subjects of future research.

The main argument of this essay is that if buildings in the past dealt with climate passively, that is, solely by their design and building materials, these old buildings should be revisited and the features responsible for tempering climate enhanced. A general review of museum buildings is proposed, focusing on their original architecture and use, so as to assess rejuvenation of their original physical qualities as a new preventive conservation approach, thereby providing an alternative to remedial actions. Prior to intervention, the design and fabric of

buildings and their performance in local climates should be assessed for visitor safety and comfort and for the conservation of the artworks they house.

An evaluation of PREMA documentation showed that the training program took both remedial and preventive actions when approaching African museums, due to the appalling physical conditions of their collections. They were the focus of the training program. Emergency tasks were prioritized and delivered throughout this outstanding 10-year project. Building problems addressed included security, rising damp or leaking roofs, and dust, particularly in storage spaces: since more than 70% of the museum collections were housed in storage, these spaces were one of the priorities of the program. In this sense, PREMA made many African museum storage areas functional, making the most of the spaces available. Both participants and staff rearranged circulation and furniture areas, separating shelves from external walls, creating *chemins de ronde* and locating the collections away from openings. PREMA ultimately designed a storage building in Abidjan to deal with its warm humid climate passively.

The race against time to cover the most urgent issues related to the extensive spectrum of preventive conservation actions seems to be the main reason for museum architecture not being addressed. The absence of an architect on the training team can be felt by the lack of documentation on the museum buildings studied and improved by PREMA participants. The existing documents are very basic when compared with the collection documentation (see front page drawing). Technical drawings and photographs were missing. The participants learned to draw plans to scale, to measure the area of shelves and compare it with floor area, but

observation of building features by free-hand drawings could have helped stimulate the participants' spatial observation skills. PREMA reports seldom include information on construction materials and techniques, or descriptions of interior spaces, decoration, type of openings or finishes.

Unfortunately, most of the documentation produced by the participants remained at the host national museums, and not all copies are available at the ICCROM Archives. This documentation should be gathered and revisited, since it could be an invaluable source of information on the physical conditions of museum buildings, 17 years after the program's completion, as well as supporting future physical interventions aiming at the enhancement of those buildings.

PREMA is a role model to be followed by other developing countries that have faced similar economical and environmental problems. Latin American countries would benefit from a new version of the program that could focus on more passive, sustainable ways of approaching museum buildings and collections conservation. And one of the research's goals is to structure a preventive conservation framework in Brazil that could provide for a future development of such program.

About the author

Franciza Toledo is architect specialized in conservation of movable heritage with a PhD in museum studies. She was associated researcher at the Getty Conservation Institute and consultant on museum matters for *Fundação Vitae Apoio à Cultura, Educação e Promoção Social*, from 2000 and 2006. As a private consultant, she has researched and written articles on museum climate control, in warm-humid regions. Addresses: Rua do Giriquiti 205/09, Recife-PE, Brasil. 50.070-010. Telephone: (81) 32225542. Email: franciza_toledo@uol.com.br

References

AHONON, Leonard. 'The Living Consecration of the History of the Kingdom of Abomey – the Musée Historique d'Abomey (Benin)'. In *Museums & History in West Africa*. West African Museums Programme. Oxford: James Currey. 2000.

AMORIM, L. and C. LOUREIRO. 'O Espaço da arquitetura como objeto de conservação e restauro. In *Anais do XVIII Congresso Brasileiro de Arquitetos*, Goiânia, 2006. Goiânia: IAB, 2006. Being published.

ANTOMARCHI, Catherine. 'La grande misère des musées africains'. In *Le Courrier* n. 112, Novembre-December, 1988. Arts & Culture Section.

_____. Personal communication at ICCROM. November, 2006.

ARADEON, David. 'Collections and Museum Architecture'. In *What Museums for Africa? Heritage in the Future*. ICOM Proceedings of the Encounters. Benin, Ghana, Togo, November 18/23, 1991. ICOM: 1992. p. 175-177.

ARDOUIN, Claude D. *Mission report PREMA 89*. International African Institute – IAI / West African Museums Project. ICCROM Archives.

BAKER, Jennifer and Fred LUGANO. 'A passive approach to practical climate control'. In *Postprints of the Wooden Artifacts Group presented at the AIC 27th annual meeting*, St. Louis, June 1999. Washington: AIC, 1999. p. 34-45.

BERNARDI, A., F. BOSSI and S. VILLANTI. 'Contributions towards a "preservative" architecture analysis of the microclimate of the national library, "Marciana"- Venice'. In *International Conference on Conservation and Restoration of Archival and Library Materials*, Erice (Italy), CCSEM, April 22-29, 1996: vol. I and II. Editors: Federici, C., Munafò, P., Costantini, D. Istituto Centrale per la Patologia del Libro. Roma, Italy. Roma: Palumbo Editore, 1999. p. 111-123.

BRE *Constructing the Future*, Issue 29, Summer 2006. p.7-8.

BUCHMANN, Wolf. 'Preservation: buildings and equipment'. In *Janus: revue archivistique = archival review*, n. 1, 1998. p. 49-62. European conference on archives (5): the basics in the profession, Barcelona, Spain, 1997.

BÜLOW, A., B. COLSTON and D. WATT. 'Preventive conservation of paper based collections within historic buildings'. In *Works of art on paper, books, documents and photographs: techniques and conservation*. Contributions to the Baltimore congress, September 2-6. Eds. Vincent Daniels, Alan Donnithorne and Perry Smith. London: IIC, 2002. p. 27-31.

CABIROL, Thierry. 'Le contrôle climatique des dépôts d'archives'. In *La climatologie dans les archives et les bibliothèques: actes des troisièmes journées sur la conservation préventive*, Arles, 2 et 3 décembre 1998. Centre interrégional de conservation du livre (CICL). Arles: Centre interrégional de conservation du livre (CICL), 2000. p. 149-153.

CANADIAN CONSERVATION INSTITUTE (2000). *The Conservation of Heritage Interiors*. Preprints of the 2000 conference/symposium.

CAMUFFO et al. 'The impact of heating, lighting and people in re-using historical buildings: a case study'. In *Journal of Cultural Heritage* 5. 2004. p. 409-416.

CASANOVAS, Elias. *A arquitectura e a museologia*. Lecture given to the *Secção Regional do Sul da Ordem dos Arquitectos*. Lisbon, 2003.

CASSAR, May and W. CLARKE (1993). 'A pragmatic approach to environmental improvements in the Courtauld Institute Galleries in Somerset House'. In *ICOM-CC 10th Triennial Meeting*, Washington DC.

CHRISTOFFERSEN, Lars (1995). *ZEPHYR: Passive Controlled Repositories*. Department of Building Physics, Lund University, Sweden. Published PhD thesis.

CULLHED, Per. 'The Almedalen Library – and Energy Low-cost Solution'. In *International Preservation News*, n. 37, December 2005.

DANIEL, V. et al. 'Stories from historic buildings'. In *ICOM-CC 14th Triennial Meeting*, The Hague, September 12-16. London: James & James, 2005. p. 625-631.

_____. 'Behaviour of Museum Buildings in Tropical Climates'. In *IIC Tradition and Innovation Advances in Conservation*. Melbourne Congress, October 10-14, 2000. p. 45-49.

ELHOUAR, S. and M. MHIRI. 'Rehabilitation of the Hotel Africa Building'. In *Structural studies, repairs and maintenance of heritage architecture IX*. Malta. Eds. Brebbia, C.A. and Torpiano, A. Southampton: Wit Press, 2005. p. 621-630.

ELOUNDOU, Laxarre. 'The traditional conservation of the Mousgoum hutshells'. In *Traditional conservation practices in Africa*. Ed. Joffroy, Thierry. ICCROM Conservation Studies 2. 2005.

GAMAL, M. and M. SELIM. 'Rehabilitation of historical buildings. Evaluation of policies and project outcomes in the Middle East: the case of Egypt'. In: *Structural studies, repairs and maintenance of heritage architecture IX*. Malta. Eds. Brebbia, C.A. and Torpiano, A. Southampton: Wit Press, 2005. p. 421-431.

GEVA, A. 'The use of computerized energy simulations in assessing thermal comfort and energy performance of historic buildings'. In *Structural studies, repairs and maintenance of heritage architecture IX*. Malta. Eds. Brebbia, C.A. and Torpiano, A. Southampton: Wit Press, 2005. p. 587-596.

GIOVANNINI, Andrea. 'Architecture et préservation: même combat = Architecture and preservation: fighting the same battle'. In *International preservation news*, N. 22-23, 2000. p. 4-18.

GUICHEN, G. 'Calling the reserves into question'. In *What Museums for Africa? Heritage in the Future*. ICOM Proceedings of the Encounters. Benin, Ghana, Togo, November 18/23, 1991. ICOM: 1992. p. 187-189.

_____. Personal communication at his house on November 10, 2006.

GUT, Paul and Dieter ACKERKNECHT. *Climate Responsive Building*. SKAT, Swiss Center for Development Cooperation in Technology and Management, 2005. 2nd edition.

HERITAGE COLLECTIONS COUNCIL. *Guidelines for Environmental Control in Cultural Institutions*. The Consortium for Heritage Collections and their Environment. Commonwealth of Australia. 2002.

HOLBROOK, Andy. 'Coping with the Climate'. In *ICON News*, 51, September 2006.

HOLMBERG, J. G., and T. BURT. 'Preventive conservation methods for historic buildings: improving the climate by changes to the building envelope'. In *Conservation without limits: IIC Nordic Group XV Congress*, August 23-26, Helsinki, Finland: IIC Nordic Group, 2000. p. 71-88.

- JAHAN, Monowar. 'Hot and humid climate: a challenge for conservators'. In *Control of Museum Climate in Asia and the Pacific Area*. Preprints of the IIC Kyoto Meeting, September 18, 1988.
- IZARD, Jean-Louis. 'La conception architecturale des locaux d'archives, une application des principes bioclimatiques'. In *La Climatologie dans les Archives et les Bibliothèques, Actes des Troisièmes Journées sur la Conservation Préventive*. Arles, Décembre 2-3, 1998. Centre de Conservation du Livre, 2000.
- KE-JIAN, Yuan. 'Short notice about the climate control of storage room'. In *Control of Museum Climate in Asia and the Pacific Area*. Preprints of the IIC Kyoto Meeting, September 18, 1988.
- KING, S., V. DANIEL and C. PEARSON. 'Airconditioning Small Tropical Museums: A Technical Note'. In *AICCM Bulletin*, December 2000, p. 33-36.
- KNUDSEN, L. and M. RASMUSSEN. 'Building a new shared storage facility for 16 museums and archives'. In *ICOM-CC 14th Triennial meeting*. The Hague, September 12-16. London: James & James, 2005. p. 648-654.
- KWAMI, Marck and Gisèle TAXIL. 'The Nankani tradition of decorated dwellings'. In *Traditional conservation practices in Africa*. Ed. Joffroy, Thierry (ICCROM Conservation Studies 2). 2005.
- MAEKAWA, S. and F. TOLEDO. 'Sustainable Climate Control for Historic Buildings in Subtropical Climates'. In *Environmental Management and Health*, Vol. 14, issue 2, June, 2003. Emerald: United Kingdom.
- MAEKAWA, S., F. TOLEDO and R. ARRAES. 'Um sistema de controle climático para a reserva técnica etnográfica do Museu Paraense Emílio Goeldi, Belém, Pará'. In *XII Congresso Nacional da ABRACOR*, Aug. 28 to Sep. 1, 2006, Fortaleza, Ceará, Brasil. Being published.
- MAEKAWA, S., C. CARVALHO and F. TOLEDO. 'Instalação de Sistema para Controle Ambiental na Biblioteca de Rui Barbosa'. In *XII Congresso Nacional da ABRACOR*, Aug. 28 to Sep. 1, 2006, Fortaleza, Ceará, Brasil. Being published.
- McDONALD, Travis. 'Understanding Old Buildings: The Process of Architectural Investigation'. In *The preservation of historic architecture – the US Government's official guidelines for preserving historic*

homes. The Department of Interior. Guilford, Connecticut: the Lyons Press, 2004. (<http://www.cr.nps.gov/hps/tps/briefs/brief35.htm>).

MICHALSKI, Stefan. 'Climate control priorities and solutions for collections in historic buildings. In *Forum*, Vol. 12, N. 4. 1998. p. 8-14.

ODDOS, Jean-Paul. 'La prise en compte de la conservation préventive dans un projet'. In *La Climatologie dans les Archives et les Bibliothèques, Actes des Troisièmes Journées sur la Conservation Préventive*. Arles, Décembre 2-3, 1998. Centre de Conservation du Livre, 2000.

OLIVER, Paul. *Encyclopedia of Vernacular Architecture of the World*. Cambridge: Cambridge University Press. 1997.

PADFIELD, Tim. *Humidity buffering by absorbent materials in walls*. 1999. Access on November 6, 2006. (<http://www.natmus.dk/cons/tp/wallbuff/wallbuff.htm>).

_____. 'The window in its context – the interplay between building components'. In *CoOL*, 2002. (www.cool.palimpsest.stanford).

PADFIELD, Tim and Poul LARSEN. 'How to design museums with a naturally stable climate'. In *Studies in Conservation*, Vol. 49, N. 2, 2004. p. 131-137.

_____. 'Low-energy air conditioning of archives'. In *ICOM-CC 14th Triennial Meeting*, The Hague, September, 12-16. London: James & James, 2005. p. 677-680.

PARK, Sharon. 'Heating, Ventilating, and Cooling Historic buildings: Problems and Recommended Approaches'. In *The preservation of historic architecture – the US Government's official guidelines for preserving historic homes*. The Department of Interior. Guilford, Connecticut: the Lyons Press, 2004. (<http://www.cr.nps.gov/hps/tps/briefs/brief24.htm>).

PINZUTI, Noël. 'Le bâtiment de conservation des archives départementales de la Corse du Sud: analyse comportementale'. In *La Climatologie dans les Archives et les Bibliothèques, Actes des Troisièmes Journées sur la Conservation Préventive*. Arles, Décembre 2-3, 1998. Centre de Conservation du Livre, 2000. p.171-176.

PRADIE, Bénédicte. *La gestion des Musées – Dossier d'Experts*. Editions de La Lettre du Cadre Territorial. s/d. ISBN 2841300471.

PREMA 1st National/Sub-regional Course Final Report. Ghana, 1989.

PREMA 2nd National/Sub-regional Course Final Report. Ivory Coast, 1990/91.

PREMA 3rd National/Sub-regional Course Final Report. Zambia, 1991.

PREMA 4th National/Sub-regional Course Final Report. Benin, 1992.

PREMA 5th National/Sub-regional Course Final Report. Madagascar, 1994.

PREMA 6th National/Sub-regional Course Final Report. Zimbabwe, 1995/96.

PREMA 7th National/Sub-regional Course Final Report. Guinea, 1996.

PREMA 8th National/Sub-regional Course Final Report. Malawi, 1997/98.

PREMA 9th National/Sub-regional Course Final Report. Ethiopia, 1999.

RANDL, Chad. 'The Use of Awnings on Historic Buildings: Repair, Replacement & New Design'. In *The preservation of historic architecture – the US Government's official guidelines for preserving historic homes*. Guilford, Connecticut: the Lyons Press, 2004. (<http://www.cr.nps.gov/hps/tps/briefs/brief44.htm>)

SANGIORGI, Franco. 'Recovery and reuse of traditional rural buildings in Italy'. In *The first international conference on archaeology and conservation*, August 12-17, 2002, Akasheh, Jordan. Ed. Talal S. Hashemite University. Granada: Fundación El Legado Andalusi, 2004. p. 401-411.

SMITH, Baird. 'Conserving Energy in Historic Buildings'. In *The preservation of historic architecture – the US Government's official guidelines for preserving historic homes*. Guilford, Connecticut: the Lyons Press, 2004. (<http://www.cr.nps.gov/hps/tps/briefs/brief3.htm>)

STANIFORTH, S. 'Environmental control in historic buildings'. In *Transactions ASCHB*, Vol. 20, 1995. p. 33-42.

STONE, S. 'Re-readings: the design principles of remodelling existing buildings. In: *Structural studies, repairs and maintenance of heritage architecture IX*. Malta. Eds. Brebbia, C.A. and Torpiano, A. Southampton: Wit Press, 2005. p. 125-134.

STANIFORTH, S and K. LITHGOW. 'When Conservator Meets Architect and Engineer'. In *Conservation of Historic Buildings and their Contents: Addressing Conflicts*. Eds. David Watt and Belinda Colston (). Shaftesbury: Donhead, 2003. p. 66-79.

STANLEY-PRICE, N. 'Movable:Immovable – A Historic Distinction and its Consequences'. In *Conservation of Historic Buildings and their Contents: Addressing Conflicts*. David Watt and Belinda Colston (editors). Shaftesbury: Donhead, 2003. p. 14-27.

_____. Email message sent to the author on November 25, 2006.

TAPOL, Benoit de. 'L'impact des publications scientifiques et de vulgarisation sur les comportements en conservation préventive dans les archives et les bibliothèques'. In *La Climatologie dans les Archives et les Bibliothèques, Actes des Troisièmes Journées sur la Conservation Préventive*. Arles, Décembre 2-3, 1998. Centre de Conservation du Livre, 2000.

_____. 'Conservation du mobilier des maisons coloniales-musée: ventilation, aération ou isolation?'. In *La Conservation Préventive*. A.R.A.A.F.U. 1992. 23-28.

TAYLOR, J. et al. 'Reviewing past environments in a historic house library using building simulation'. In *ICOM-CC 14th Triennial meeting*. The Hague, 12-16 September. London: James & James, 2005. p. 708-715.

TAYLOR, Joel. 'Negotiating the climate: a plan for the appraisal of control options in historic houses'. In *The Conservator*, N. 26, 2002. p. 85-92.

TOLEDO, Franciza (1999). *Passive Environmental Control for Museums in Hot-Humid Climates: Guidelines for Building Design and Fabric Improvements*. PhD thesis. Institute of Archaeology, University College London, University of London.

TOMBAZIS, A., N. VRATSANOS and S. PREUSS. 'Guidelines for the design and retrofitting of energy-efficient museums for antiquities in the Mediterranean countries'. In *ICOM-CC 12th Triennial meeting*, Lyon, Aug. 29 - Sep. 3, Vol. 1. London: James & James, 1999. p. 106-112.

UGHENU, Vincent. 'Museums as a Source of History (Nigeria)'. In *Museums & History in West Africa*. West African Museums Programme. Editors: Claude Ardouin & Emmanuel Arinze. Oxford: James Currey. 2000.

ZONG, Zhou Bao. 'The measures of Controlling the Environment Climate in Museum'. In *Control of Museum Climate in Asia and the Pacific Area*. Preprints of the IIC Kyoto Meeting, September 18, 1988.