Sustainable Conversion of historic buildings in Cuba: the case of Santo Domingo de Atares Castle, Havana

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Sustainable Conversion of historic buildings in Cuba: the case of Santo Domingo de Atares Castle, Havana

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Abstract

Recently, in the Cuban capital of Havana, a number of fortresses were given away by the Army for refurbishment and conversion to public functions. In the last two decades, there have been examples of refurbishment and conversions of fortifications in museums, some of them with dire consequences for the collections and the structures. In this type of structure every architectonical element has historic value and very few interventions are allowed. However, the accommodation of modern functions and the preservation of the structure heavily rely upon the balance between various environmental parameters of the interior spaces. This study explores the challenges and opportunities of an environmentally driven conservation approach to the refurbishment of one of Havana's most iconic XVIII century's defensive structures, Santo Domingo of Atares Castle. The paper illustrates the development of an architectural proposal for the conversion of the castle into a museum and associated energy and environmental strategies. The museum function is particularly demanding due to the rigorous standards for the preservation of the collections, generally accomplished by mechanical equipment. Recently, however, there has been a major concern in the conservation scene about energy consumption and sustainable practices in this type of buildings. Therefore, the work identifyies the characteristics of the existing climatic and environmental conditions affecting the interior spaces of the thermally heavyweight fortress. This has led to an analysis of the requirements of the collection in a hot-humid climate in conjunction with the parameters for human comfort, in order to identify to what extent the original conditions can be passively modified to adapt the building to the conversion. Finally, with the help of computational dynamic simulations, passive strategies and zoning options were tested for the achievement of suitable interior environmental conditions and subsequent energy savings.

Keywords: environmental strategies, conservation, hot-humid climate

1. Introduction

In the current context of historic buildings conservation there is widespread acceptance of functional change and architectonic alteration for the sake of economic benefit produced by increased tourism and investment attraction (Glendinning, 2013). In a world were cultural significance is so relative, environmental criteria should support informed conservation decisions, reduce environmental impact and ultimately offer an energy efficient building in which people feel in comfort.

In general, the most important parameters to control in a museum environment are temperatures (Dry Bulb and Resultant), Relative Humidity (Rh) and Illuminance levels (Dean, 1994). The standards for temperature and RH are easily achievable in temperate climates, however, in hot ones dependence on air conditioning systems seems to be the only solution. Nevertheless, the ideal of a standard environment is relative, what is important is stability and reduced variation. In that sense, tropical climates are characterized by steady values of temperature and RH throughout the year. Biodeterioration, however, is the principal risk and RH values of more than 70% must be avoided (Toledo, 1999).

2. Climatic and environmental context

It can be thought that Cuba's climate is very hot, however temperatures rarely surpass 35°C. If the comfort band is calculated according to ASHRAE 55 in the hottest month, the upper limit will be around 28oC. Nevertheless Cuban regulations recognize the potential for adaptive comfort and the effect of natural ventilation and acclimatisation and have established 30oC as the maximum limit if there is air movement in the space. The determined design sky for Cuba is 13 000 lux and for Havana, it was tested that this value is reached between 78 and 88% of sun-hours (Diaz and De la Peña, no date).

Regarding RH, there is a constant transport of water vapour from the sea to the land, favouring the occurrence of very high values. During evenings and nights, when the air temperature reaches its lower values it is observed almost every day values of RH higher than 90%, arriving to saturation with high frequency. During daytime, RH reaches the minimum value at 1pm between 30 and 50%, depending on the time of the year and region of the country. Therefore, it is unlikely that the maximum values of RH and air temperature coincide daily. The average daily range of RH is between 50 and 60%, however the range of the temperature is about 10 degrees (Alemany, 1986).

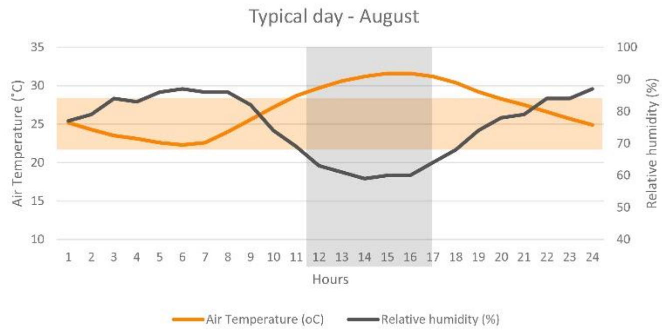

Figure 3. Temperature and RH in a typical day in August (after Meteonorm v. 7.0)

Therefore, the most appropriate benchmarks applicable to the interior spaces of Atares Castle, are for human comfort 30oC for the upper limit of the Resultant Temperature, assuming presence of air movement. For the da Vinci's artefacts preservation, RH <70% and illuminance <200 lux.

3. The building

Santo Domingo of Atares castle was recently given away by the Cuban Army to the Office of the Historian with the objective to restore and adapt it to museum. It was decided that the building will not only show the history of the fortification but also it will house a collection of Leonardo Da Vinci replica artefacts, built from wood, leather and textiles. In total the collection has 52 pieces, of them 27 are miniatures to be exhibited in glass cases, 6 are large pieces to be observed at a distance and 19 are big artefacts which require certain level of interaction.

Figure 1. Entrance of Atares castle

Figure 2. Da Vinci's artefacts

Atares Castle was designed by the Belgian military engineer Agustin Crame. It was part of the new defensive system created after the English attack to Havana (Quesada, 2013).

The fortress is located in Soto hill, in the southern portion of Havana's bay. It is popular known as castle, but the classification given by its planners was "battery". The trace is an irregular hexagon without bastions with echaugettes or garitas in its 6 corners. The fortress has a ditch and a covered way surrounding the building, also with echaugettes. The interior is structured by vaults surrounding the place-of-arms, under which there are two "aljibes" (cisterns) and in one of the corners there is a stoned stair which lead to the esplanade, where the artillery was located. One of the biggest changes in the structure concerns the openings in the envelope. Original windows and unprotected openings (holes) in the roof were of about 40cm, but the existing ones are larger. This was due to an intervention done in 1901 by the American Army (Quesada, 2013).

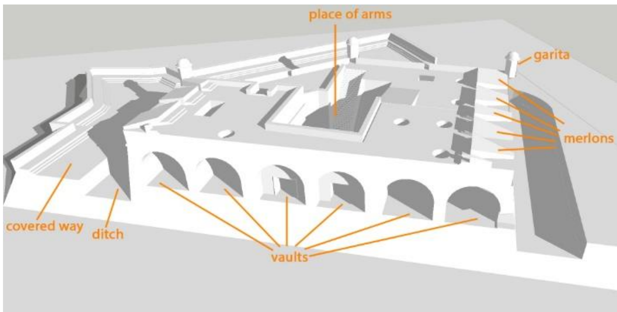

Figure 4. Structure of Atares castle

Nowadays, due to the fact that Atares castle belongs to the ancient Havana's defence systems, it is considered World Heritage and has Grade I of protection for its uniqueness. This denomination implies heavy restrictions respecting possible interventions and uses.

4. Environmental Performance

Due to the impossibility to visit Atares castle during the development of the project and to carry out direct fieldwork, the current performance of the castle was analysed using dynamic thermal modelling and simulation.

4.1. Base cases

In characterising the base line performance of the current scenario it was decided not to have a single base case, but several ones in which every element of the envelope was assessed in its influence in the performance of the interior spaces. The software used for these simulations was TAS EDSL. The whole castle was modelled, but only the main vaults were zoned and their performance simulated. The results were assessed with the achievement of less than 70% in RH. For resultant temperature it was used as benchmark the ASHRAE comfort band (adaptive method) for the lower limit, along with 30 degrees as the maximum limit, based on the Cuban Regulation NC-19-01-03, during the open times of the museum (10am to 5pm). It was chosen days 15 (January 15^{th}) and 227 (August 15^{th}) not only because they represent typical days in the dry and rainy season, but also because the first is cloudy and the latter is sunny to test the influence of the direct solar radiation.

The first base case was designed to evaluate the influence of the heavy mass (4 meters thickness exterior walls and 1.5 meters roof), without openings. The second case allowed to test the impact of solar radiation entering the interior spaces by the windows. The third one looked at the influence of the roof's holes in the solar gains. The base case 4 looked at the building in its current state with 24 Hours natural ventilation.

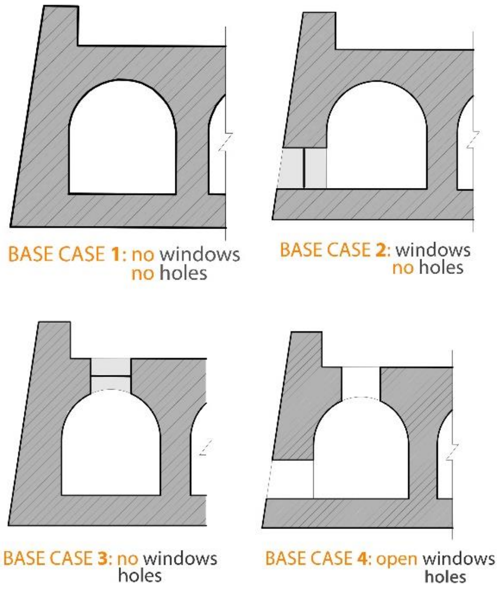

Figure 5. Parametric and incremental analysis of the base case

These simulations showed that the heavy mass of the building can give stability in the parameters, good values of RH can be obtained, however temperatures are higher than the outside peak. The higher values of temperatures are in Case 3 and show that most of the solar radiation is received by the roof and the openings on it. Ventilation can bring lower temperatures, but also instability in RH. Throughout the cases all vaults have similar performance.

5. Environmental Strategies

If mechancial systems are installed in the building to achieve thermal comfort and dehumidification, blackouts and routine power cuts could have catastrophic consequences for the preservation of the collection. Also, the installation and camouflage of the equipment would be unsightly and damaging for the structure itself. For that reason, various passive and hybrid strategies were explored to address the above mentioned and other equally important risks such as that over overillumination and excessive solar gains through the openings.

5.1. Daylighting and Solar Control

In order to see the influence of windows and roof openings in the level of illuminance in the vaults, simulations with the software Radiance were performed. The benchmark to prevent light damage in pieces like the artefacts is 200 lux. It was observed that in some areas the openings in the roof produce more than 1000 lux of illuminance with an intermediate sky. Several options for the restricition of roof openings and windows were tested, and the final proposal with acceptable values was to cover windows and roof openings with louvers. This was beneficial for both the thermal performance and dehumidification, by reducing the ingress of solar radiation and allowing the integration of passive and hybrid dehumidification strategies.

5.2. Natural Ventilation and Thermal Comfort

Despite of the results of the initial simulations, natural ventilation was further studied because is totally passive and in Cuba's climate it allows to achieve comfort with temperatures over 30oC (De la Pena, no date). Furthermore, the ingress of polluted air from outside is not a problem in the castle because it is located at the top of Soto hill, which is completely covered by vegetation.

It was decided to test different schedules of natural ventilation with the actual building's envelope combined with the best daylighting solution of windows and roof openings and with the internal gains that a museum of this type in Havana can have in terms of occupancy (10 persons in each room). The first scenario was with windows and holes open the whole day. The second was applying night-time ventilation when temperatures are lower. The final one, was to test if RH can be controlled effectively opening the building during the visiting hours (from 10am to 5pm) in which the exterior RH is at its lowest point.

This set of simulations showed, that 24 hours ventilation, as expected, brings instability, lower temperatures are reached throughout the year, but RH changed from nearly 90% to 50% in one day. In the second scenario lower temperatures were expected because this is a strategy used normally in high mass buildings. The maximum peak temperature of the day was reduced but RH was too high during the night.

In the last case, RH was most of the time under 70%, the temperature was stable, but very close to the peak value of the day. This last scenario had the best results for the pieces' preservation, stability and low RH. However, the Resultant Temperature was in multiple occasions above 30oC.

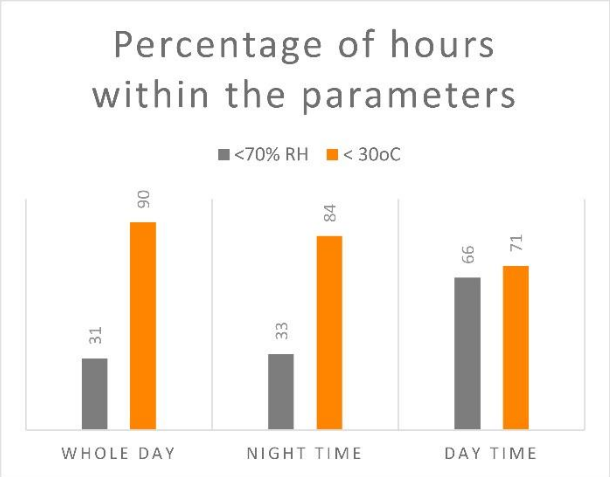

Figure 6. Results of the simulations for natural ventilation strategies

Alternative approaches can be used to address the problem of resultant temperatures above the upper limit of the comfort band. For example, the concept of positive alliesthesia offers great potential (Parkinson & de Dear, 2015). In this sense, air movement or temperature drifts can create a pleasant perception of the space even with high values of temperature. Fans and the movement of the visitors through the different spaces of the castle with different environmental conditions can bring the desirable comfort perception.

5.3. Dehumidification

To apply dehumidification, mainly during the night time was another tested strategy. The dehumidification device chosen was silica coated louvers encased in glass panels applied to the openings in the roof. This can work either passively or in mechancial mode, where an automatic control system could mechanically force humid air in the night to go through the louvers, adsorbing the moisture and releasing drier air to the inside. According to Chenvidyakarn (2007) a device like this would have a capacity of 4-5 g/kg humidity reduction. However, a decrease of 20-30% in RH cause an increment in the temperature of about two to five degrees (Takagi, 2011; Chenvidyakarn, 2007). The recharge of the system would happen in the day when solar radiation and circulation of hot air between the glass panels remove the moisture from the silica.

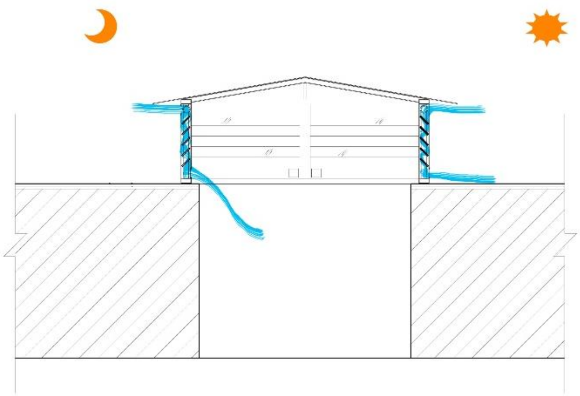

Figure 7. Dehumidification device functioning during nights and days

Using TAS simulation software it was decided to take as function for the hygroscopic device a 20% reduction of RH and 2oC temperature increase of the incoming air. The strategy to emulate the dehumidifier was to create a "dummy" zone where the temperature and RH was set hourly, and the value of air flow entering the interiors was of 1kg/s per each hole, one window in every space was kept open. This method was used to perform the simulation for one representative day, therefore it was chosen a typical day in August. The resultant temperatures and RH values were compared with the ones from the Day time ventilation scenario. The RH values were acceptable and the temperature was about 2-3 degrees lower. Despite this favourable result, it was decided then to take one day in which the open day ventilation does not work keeping RH below 70% and to test the dehumidifier. The result was disappointing, RH values during the whole day were so high that dehumidification only during the night is not enough. A different strategy was tested using the dehumidifier the whole day, and the values of RH were reduced but the temperature was higher. As a conclusion it can be said that the silica coated louvers give acceptable levels of RH and even better resultant temperatures for 24 hours in typical days. For extremely humid days, the system can be used 24 hours, but only as a contingency plan because recharge time for the release of moisture is essential.

6. Final proposal

In general, it can be said that according to environmental requirements there are two types of spaces needed in the fortress, those that are housing the Da Vinci's replica artefacts and which require control of RH and those that are housing other functions in which humidity control is not an issue. It was decided that day-time ventilation or silica coated louvers dehumidifiers with night-time ventilation strategies can be applied in the spaces where the artefacts are located, to keep RH below 70%. Ideally RH and Temperature activated automatic control system in charge of the opening/closening of the roof openings and louvres should be installed but a seasonal and time based manual control system is also a robust alternative and could make the control cheaper and less dependent on energy. Additionally low wattage ceiling fans are reccommended to give visitors increased air movement and improved comfort perception.

According to the daylight analysis, windows must have louvers to control the amount of light and solar radiation entering the space. However, the need for night time ventilation for dehumidification and theneed to eliminate ventilation during the opening times of the museum, conflicts with the daylighting requirements. Therefore, every window in the artefacts' rooms would have two layers, one of louvers and the other of glass, giving multiple choices for air and light entrance, which is a common characteristic of the traditional Cuban windows.

Due to the building's configuration it is not possible to do a lineal itinerary throughout the rooms, the place of arms will serve as main circulation area. Therefore, the visitors need to go out to the patio to go inside of each room. This will bring different perceptions and will trigger positive alliesthesia (Parkinson & De Dear, 2015) when the visitors entered the exhibition rooms. The sensation when entering the vaults will be of a cooler environment because of the difference between shady and darker space in comparison with the brighter and sunny courtyard.

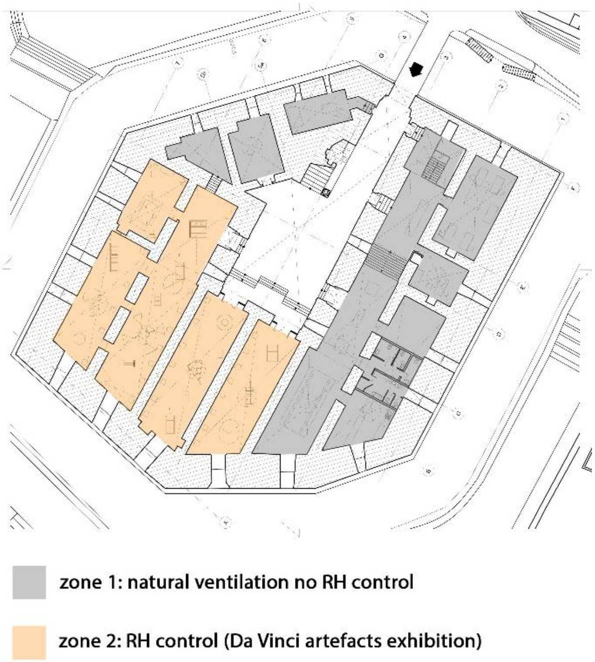

Figure 8. Zoning of the different areas in the castle

The other spaces as the reception, tickets office, café and offices will be located as close to the entrance as possible. In this way, whole day natural ventilation can be applied, and human comfort with Resultant Temperatures below 30oC will be achieve for most of the time (87.6%) without the use of any kind of active strategy.

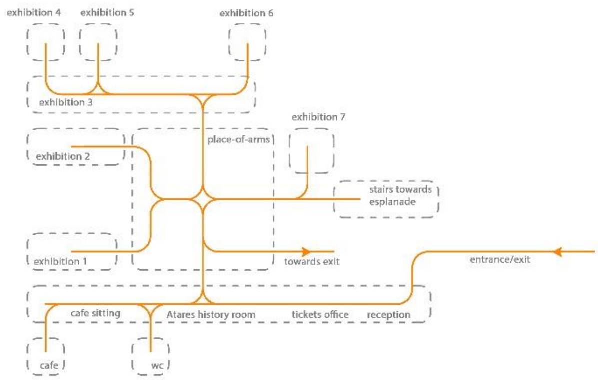

Figure 9. Movement of the visitors in the castle

7. Conclusions

In the process of making a sustainable architectonical proposal for a museum in Atares castle diverse and challenging issues were considered. Also, traditional standards for museums were challenged in their effectiveness and applicability to hot-humid climates.

Figure 10. One of Da Vinci's artefacts rooms

The performance analysis proved that passive strategies can be applied for the environmental control of a museum. Althought it would be impossible to meet the desired environmental values for 100% of the time with the proposed strategies, it would be worst to have a drastic change in the environment caused by a defective equipment or power cut due to exceeded maxium electrical load. The proposal has two feasible options for the control of the Da Vinci's replicas rooms. The first one is with an experimental dehumidifier, giving good results for typical days and an alternative for untypical ones. On the other hand, a completely passive and low-cost strategy proved to be acceptable for more than 60% of the time and in its achievement of human comfort it was proposed an alternative approach using the concepts of positive alliesthesia. Economical and practical elements must be taken in consideration to decide which strategy is the best, nevertheless in the Cuban context and climatic conditions the strategy of day-time ventilation has greater feasibility and stronger applicability.

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