# SUSTAINABLE ARCHITECTURE AND ENERGY EFFICIENCY IN A RETROFITTED MUSEUM

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## ABSTRACT

The Portuguese National Museum for Archaeology is undergoing an expansion and retrofitting. It is currently housed in one of the most important ancient monuments in Portugal: the Monastery of Jerónimos. The authorities responsible for the museum, taking advantage of this retrofitting, decided to promote a modern and integrated design of the future archaeological museum. The architectural design aims to combine, aesthetically, the old and the new building, promoting sustainable architecture and energy efficiency (concerning, essentially, indoor climate, lighting and acoustical requirements). This paper presents the energy study of the future museum. It shows the modelling process, the thermal simulation results for sizing and optimising the HVAC system and also an economical analysis of several possibilities for providing heating and cooling to the museum power plant, including conventional and renewable sources of energy. The results show that, once the building shell is optimised and loads reduced, the conventional solutions for the power plant with state of the art equipment are still, in pure economic terms, more attractive than other less common alternative solutions.

## KEYWORDS

Museum retrofit, energy simulation, HVAC system, energy efficiency, geothermal resources.

## MUSEUM DESCRIPTION

The National Archaeological Museum (Lisbon, Portugal) is housed in the Jerónimos Monastery (Figure 1), in an historical zone of the city.

Figure 1: Front view of the Museum

This monastery is one of the most important ancient monuments in Portugal. It was ordered built by king D. Manuel I, in 1501, to celebrate the Portuguese Maritime Discoveries. In 1907 it was classified as a National Monument in Portugal and in 1984 a “World Heritage Site” by UNESCO.

## Present situation

The National Archaeological Museum is located, since 1903, in the south wing of the Monastery. The other spaces are occupied by the Navy Museum (Figure 2).

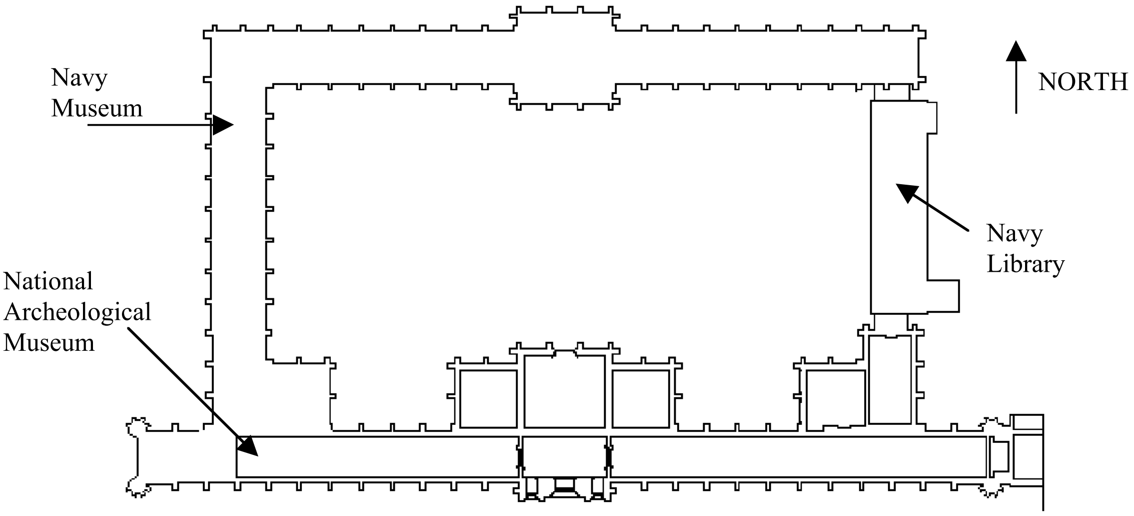

Figure 2: Plan view of entire existing building

Currently, the museum uses two floors, with a total floor area of 5192 m$^2$. The reception and all the exhibition spaces are in the ground floor. There are two small spaces to exhibit special collections (gold collection and egyptian artefacts) and two main galleries for other exhibitions (Figure 3). Excluding the two small rooms for the special collections, which are fully air-conditioned, there is no indoor environmental control in this floor. The first floor houses the administrative and technical offices, laboratories, storerooms and a library. This floor has no indoor environmental control, except for small electric heaters in a few offices.

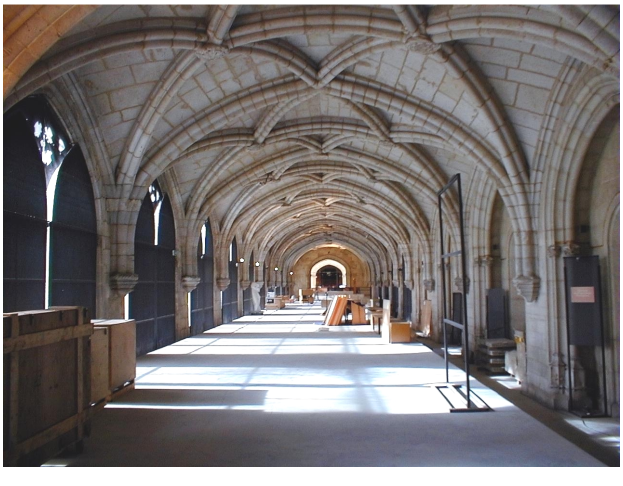

Figure 3: Ground floor view

## Future Situation

The museum is undergoing an expansion and retrofitting. It is to be upgraded and extended to about twice its present useful area. The main objective is to double the exhibition area, also using the whole first floor for this purpose. All the necessary space to storerooms, technical and administrative offices, laboratories, and rooms to prepare the exhibitions will be moved to a new addition, to be constructed underground in the courtyard of the Monastery (Figure 4). The exhibition areas in the existing building will communicate with the addition through two underground corridors. Two small towers adjacent to the existing building will be retrofitted to offer support services to the visitors, namely, a reading room, an auditorium, a coffee house, a shop, etc. The final area of Museum will be 10762 $m^2$ (6308 $m^2$ in the existing building, including the two small towers, and 4454 $m^2$ in the expansion).

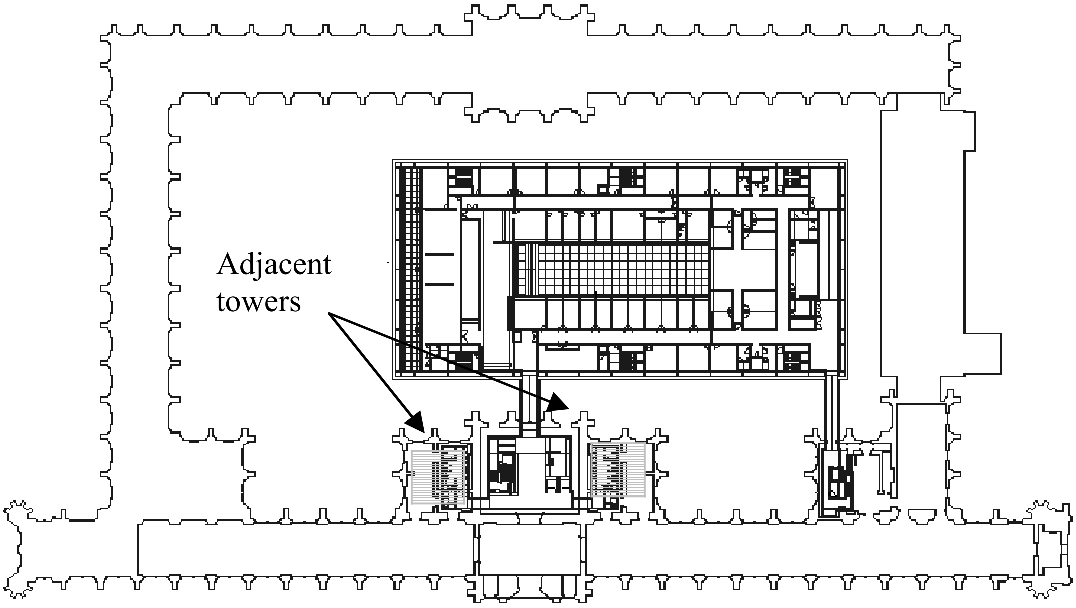

Figure 4: Plan view of entire existing and new building

## ENERGY ANALYSIS

The design of the museum expansion and retrofitting will pay a very special attention to energy performance. The best possible indoor environment must be assured, in both the exhibition and working spaces, concerning heating, cooling, ventilation, lighting and acoustic comfort. All the building energy demands must be minimized. So, the design involved an optimisation of the building envelope without compromising the visible aspects related to its character as a National Monument and a careful control of internal loads to minimize cooling needs (in particular the electric lighting loads). Moreover, a special attention has been given to the dynamic aspects of the building, taking advantage of the high inertia of the existing building as well the new underground expansion to optimise cool-down and heat-up periods. As shown in Figs 2 and 3, the Monastery has thick (1m), uninsulated, limestone walls. The floor and ceiling are also made of thinner (1m) limestone blocks in the ground floor but they are made of wood in the upper floor gallery. The inertial behaviour of these two types of spaces is quite distinct. The ground floor has such a stable behaviour without any AC, as shown in Figure 5, that no mechanical cooling systems are really needed in summer.

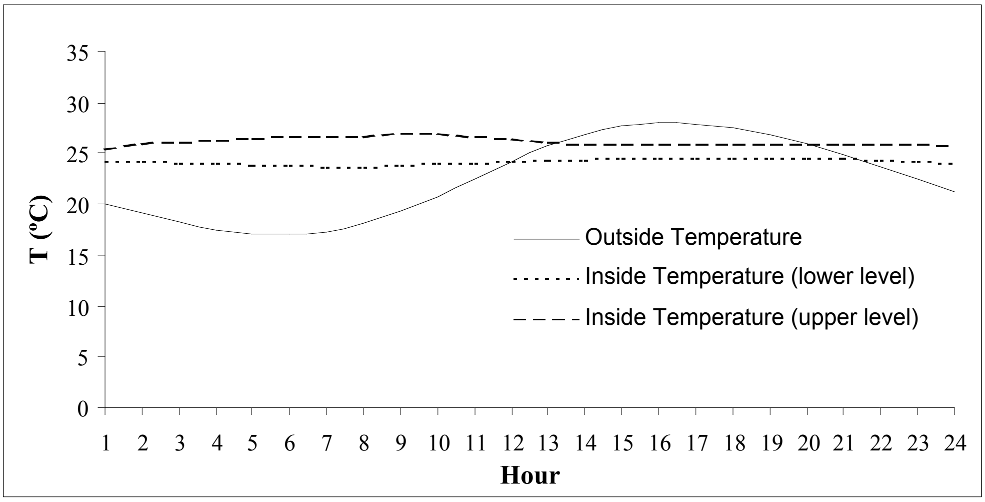

Figure 5: Inside and outside temperature in a typical summer day

## HVAC solutions

The museum will be equipped with different HVAC solutions for the various types of spaces:

- The exhibition galleries in the ground floor shall have a heated floor to bring indoor temperatures to the comfort levels - presently, they are very stable but quite cold (14 ºC) during the winter months.
- The exhibition galleries upstairs shall have an all-air system. Several air-handling units with the possibility for free-cooling and heat recovery will be placed in the attic space.
- In the newly retrofitted adjacent towers and the new underground expansion, loads are to be handled by fan coil units in each space. A separate fresh air ventilation system shall supply air at close to neutral temperature to each space, as needed. As occupation of these spaces is rather uniform over time, modulation of supply air rate is not justified. A few individual offices may be equipped with daylighting units, which may also offer the possibility of natural ventilation.

## Energy simulation

A careful dynamic simulation of the building and its HVAC system was carried out using Visual DOE2, Eley et al (1996), for sizing and optimising the system, including improved daylighting of the monastery galleries and roof insulation. The simulation model used for the Museum was multizone, considering the different types of spaces in the existing building and the new addition to be built. It also included consideration of heat recovery in the ventilation air and free cooling, which have been show as viable economic options for the HVAC in this building, Lima and Maldonado (2000). After a sensitivity study to define the most desirable insulation levels, it was possible to identify the total thermal needs of the building (Figure 6). The totals come up to 41.3 kWh/year↘m$^2$ for heating and 35.2 kWh/year↘m$^2$ for cooling (final thermal energy).

Once the building loads have been established, several possible scenarios for providing heating and cooling to the museum power plant have been studied in detail, including conventional and renewable sources (table 1). These several scenarios have been studied in terms of investment costs (including the cost of building space needed for infrastructure) and energy costs for annual operation, including fuel and electricity consumption. The results are shown in the Figure 7.

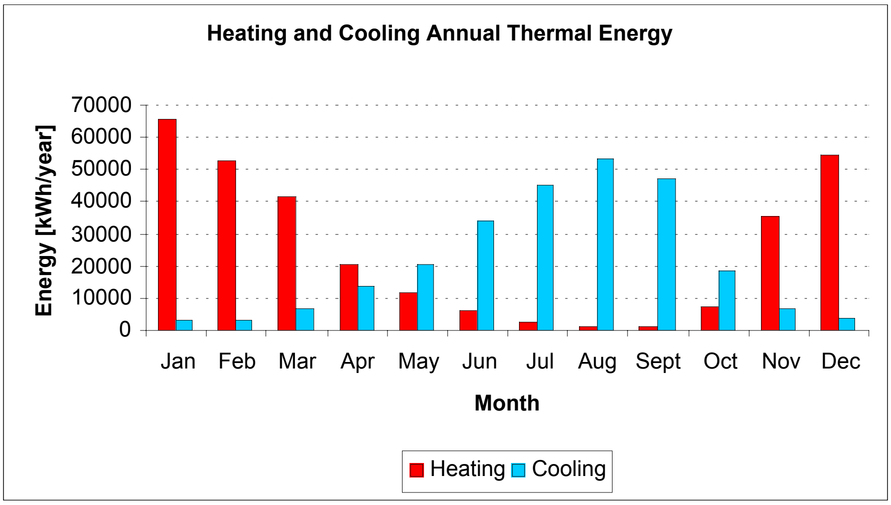

Figure 6: Heating and cooling annual thermal energy

TABLE 1
Possibilities for hot and cold water production

| Hot water production | |
|---|---|
| **Solution** | **Description** |
| A | Two condensing gas boilers |
| B | Geothermal Well at ca. 1000 m depth (40 ºC) |
| C | Three reversible water-cooled heat pumps using water from a 300 m well at 25 ºC |
| D | Three air-cooled heat pumps |
| **Cold water production** | |
| **Solution** | **Description** |
| 1 | Two air-cooled chillers |
| 2 | Two water-cooled chillers using water from a 300 m well at 25 ºC |
| 3 | Two water-cooled chillers using cooling towers |
| 4 | Three reversible water-cooled heat pumps using water from a 300 m well at 25 ºC |
| 5 | Two absorption chillers cooled with water from a 300 m well |
| 6 | Two absorption chillers cooled with cooling towers |
| 7 | Two absorption chillers cooled with water from a 300 m well and with heat recovery |
| 8 | Two absorption chillers cooled with cooling towers and with heat recovery |
| 9 | Two air-cooled compression chillers with a natural gas engine |
| 10 | Two air-cooled compression chillers with a natural gas engine and heat recovery |
| 11 | Three air-cooled heat pumps |

Taking the solution with the lowest investment cost as the reference case, it can be seen that providing heating with two condensing gas boilers is quite cost effective. All the other solutions are marginal in terms of payback, but solutions with up to 10 years payback might also be acceptable if architectural consequences also offer other advantages.

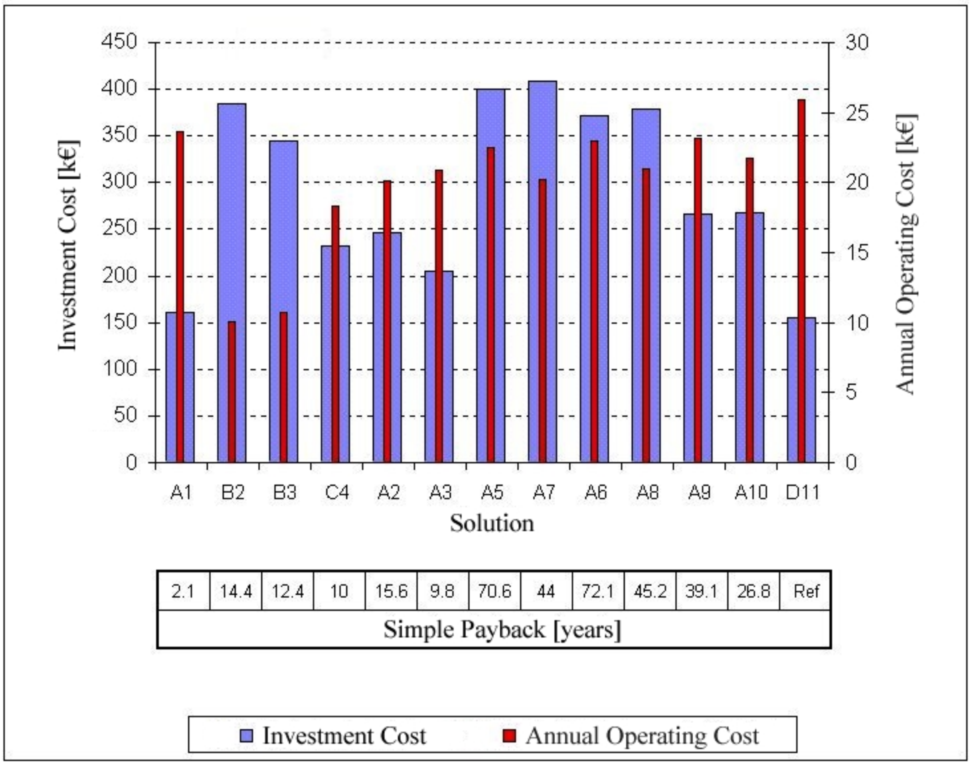

Figure 7: Economical results for several scenarios analysed

A special interest is the adoption of a geothermal well to provide heating (solutions B – direct heating and C – with heat pumps). Although this was an initial objective of this project, the economics turned out to be not very favourable. The costs of drilling the well are too high and the heating needs are not large enough to allow for recovering the costs within a reasonable period. Combining this with the increased risks this solution carries, in terms of availability of a sustained resource and corrosion due to the chemical characteristics of the water in the geothermal reservoir, it turns out that it will be difficult to implement this type of renewable solution in this building.

## CONCLUSIONS

The aim of this work was, in essence, to make an economical study of several possibilities to design the HVAC system power plant for an essentially new museum building. The idea was to compare conventional solutions (based on common boilers, chillers and cooling towers) with others no so much conventional (for example, the use of water from a geothermal well). The results showed that the conventional solutions are still more attractive under current economic conditions. The best option is still the integration of passive measures into the building envelope (insulation, daylighting, etc.) and then to use good efficient conventional heating and cooling HVAC equipment, using such techniques as heat recovery, free cooling, demand-controlled ventilation, to meet the loads. The investments in low-temperature geothermal wells can only pay off for larger building loads or when the water temperature is higher.

## REFERENCE

Lima M. and Maldonado E. (2000). STEVE - Software Tool for Efficient VEntilation systems in buildings. Users manual. IDMEC, University of  Porto.