Energy Efficiency and Sustainability in Retrofitted Museum Buildings
“A case study in Florence”

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ABSTRACT: The Historical Bardini Museum in Florence is a representative paradigm of the Italian Museum Building and is also one of the most important buildings of the Renaissance, therefore it is very suitable to serve as an exemplary pilot project for the restoration of historical museums. This paper presents results of the architectural and energy retrofitting carried out applying appropriate and strategic low energy and sustainable techniques and of the monitoring campaign performed to evaluate at first the existing situation and to verify comfort parameters and the energy consumption after works. The Bardini Museum participates, as Italian case study, to the European MUSEUMS project, financed by EU Commission in the Fifth Framework Programme. The result of this project is to provide also with a direct guidance, complete with architectural and engineering examples, for design professionals and museum authorities, setting a new standard for energy consumption in museum buildings.

The Bardini Museum project has aimed particularly at an important decrease of energy consumption and peak electricity demand for lighting, as well as to obtain a considerable improvement of comfort and indoor conditions for visitors and staff, improving at the same time the exhibit handling and display. In parallel, it has aimed to disseminate effective information and to demonstrate the efficiency of the measures in order to promote them in efficient market promotion, penetration and utilization.

Conference Topic: 2 Design strategies and tools
Keywords: museum design, energy saving

INTRODUCTION

Museums represent our cultural heritage and are buildings of great importance as well as of significant representative character. In the context of energy and the environment, museums not only constitute tens of thousands of buildings in Europe but are also visited by millions of people. Despite their importance, existing as well as new museum buildings are very rarely energy efficient and often provide dissatisfactory comfort conditions.

European Project MUSEUMS—contract no NNE5-1999-20 started in 2000 with the intention of bringing together 8 different retrofitting, conversion and new museum projects from all over Europe and a representative variety of types with the support of internationally acclaimed experts in the field of energy efficiency research in order to produce excellent showcases of energy efficient and sustainable museum design.

1. THE ITALIAN CASE STUDY: THE BARDINI MUSEUM IN FLORENCE

The building is located in the centre of Florence, near the Old Bridge. And it is detached on all sides, except on the East part and its only entrance is from the West. This building represents one of the most important buildings of the Eclectic period. It was realized by restructuring an old church with monastery in 1883 by the Italian architect Bardini to contain and show his work of art collection.

The building, according to the main characteristics of the museums typology largely spread in Italy, is a representative example for a project that aims to demonstrate that this type of historical building suits very well the application of sustainable design. It applies energy conservation systems, applying appropriate and strategic low energy and sustainable techniques for a better energy retrofitting, without altering historical characters.
2. THE DESIGN PROBLEMS

At the start of the MUSEUMS project, the building was in a general state of deterioration. The 3200 m² exhibition space, shared out on three levels, was, with the exception of administration area, no heated or cooled, there was no mechanical ventilation, or environmental control system (or surveys for thermo-hygrometric, CO2 and illumination evaluation). In fact, the building was naturally ventilated and it hadn’t any air conditioning system installed. From the architectural point of view, the heavy structure of the building, consisting of a traditional construction stone, characterised by massive walls, had many problems of obsolescence (greater humidity problems),... because of the long period of neglect. The structural and functional obsolescence, such as brought with it several consequences as:

- inadequate environmental conditions for visitors and staff related to air quality, thermal and visual quality
- no environmental monitoring and control; i.e. no controlled ventilation: unfavourable and changeable conditions for object and visitors;
- excessive energy consumption: i.e. lighting represents 70% of the total energy consumption due to insufficient and obsolete devices in the exhibition spaces, no presence detectors, no day lighting compensation system;
- no efficient use of energy due to bad building maintenance and obsolete equipments;
- damaged windows and windows frames,
- high air infiltration rates;
- inadequate exhibit handling and display;
- inadequate spatial organisation of exhibition space.

3. THE ARCHITECTURAL DESIGN

The first step of the retrofitting project was the building energy analysis and simulation, in order to single out the best design strategies to improve the thermal performances of the envelope, particularly noting that the existing facades cannot be altered.

Figure 1: the Bardini Museum in the past

The long axis of the building is North-South oriented and losses trough the envelope were mainly caused by infiltration due to poor conditions of windows, whereas an appropriate levels of insulation and decreasing of air leakage were demanded in order to achieve a reduction of convective and radiative losses.

With regard to the simulation results, main building improvements have concerned the complete roof rebuilding, increasing the covering insulation level (using a 10 cm natural cork panel, dry installed without artificial additives) and building a ventilated roof to improve added night ventilation and reduce the high thermal losses of the top floors.

Reduction of heat losses trough the transparent components has been an important problem to solve in this case study. In fact all existing windows were single-glazed, so it caused excessive heat losses in winter and uncontrolled overheating in summer. Combined with the roof insulation, all the old windows frames have been replaced with double-glazed ones, to drastically reduce the infiltration rates and assure airtightness, in order to decrease the energy demand for heating and cooling (2-5%).

Special grids have been also installed under windows to be opened during summer to improve stack effect ventilation.

The bad state of repair of all the transparent components was the cause of the high heating/cooling costs, but also of the electrical ones: the specific consumption for lighting of Bardini Museums was high, because of high lighting loads unnecessarily installed, no control, low efficiency and a poor use of daylight, in spite of the presence of a large number of skylights.

Figure 2: the existing facade

Therefore, after simulations with Radiance tool (a highly accurate ray-tracing software for predicting the distribution of visible radiation in illuminated spaces. It takes as input a three-dimensional geometric model...
of the physical environment, and produces a map of spectral radiance values in a colour image) that have shown a significant reduction of transmittance using high diffuser in place of the existing glass, the first step was to change the skylight roofing structure in the main room on the ground floor, just in front of the entrance.

**Figure 4**: the existing skylight: external view

<table>
<thead>
<tr>
<th>Table 1: comparison between the transmittance level of the old and the new skylight</th>
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<tr>
<td>Skylight roofing structure with glazing light transmittance</td>
</tr>
<tr>
<td><strong>τ = 80 %</strong></td>
</tr>
<tr>
<td>High transmittance diffuser for false ceiling with light transmittance</td>
</tr>
<tr>
<td><strong>τ = 70 %</strong></td>
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</table>

For the double structure of the central skylight, in place of the heavy glazed roofing, the project has provided external 30 mm twin-welled polycarbonate panels roofing with a special reflector that can reduce glare and increase illumination levels, whereas the lanterns of the existing wooden false ceiling have been replaced with high transmittance diffuser components made of a high-grade flexible plastic in order to assure an uniform luminance distribution at the ceiling in the room, apart of a better acoustic.

**Figure 5**: the new skylight: external view

**Figure 6**: Project section of the central skylight

**Figure 7**: the existing skylight: internal view

**Figure 8**: the diffuser panels installed on the old wooden ceiling

### 4. THE ENERGY DESIGN

#### 4.1 Simulations

In order to calculate the distribution of the indoor temperatures, as well as the energy required for heating and cooling purposes, the Esp_r software (Environmental Systems performance – Research is an integrated modelling tool for the simulation of the thermal, visual and acoustic performance of buildings and the assessment of the energy use and gaseous emissions associated with the environmental control systems and constructional materials) has been used to estimate the indoor temperatures in each zone as well as the heating and cooling loads for winter and summer period. The 3D model of the building has been divided into six thermal zones, at the ground and first floor of the building. These zones represent
the main exhibition areas and service spaces.

![Figure 3: location of Thermal Zones – ground floor](image)

ZONE 1: represents the spaces of great expositive interest, it includes four rooms at the first floor, with West-North/West orientation.

ZONE 2: it includes only an exhibition room, at the mezzanine between ground and first floor; it looks at the double volume of the atrium, included in the zone5.

ZONE 3: includes the volume of the principal staircase and two rooms of the hallway, at the first floor; one is exposed to East-South/East, while the other, it is leaned out on the double volume of the atrium without a direct opening on the outside of the building.

ZONE 4: it is the reception at the ground floor with corridors and open spaces used like connection between rooms.

ZONE 5: includes the big expositive room with the skylight at the ground floor, the atrium and the adjacent room.

A similar simulation has been done, as already said, to optimize the daylighting design phase using the Radiance tool to analyze glare problems, luminance and illuminance level ecc.

Simulations have taken into account also the interior design proposal to restore the original distempering blue colour of the walls demonstrating that it has minimal influence on the horizontal luminance, even if clearly the walls will appear darkest because of their small ability to reflect the bright rays, increasing consequently the demand of artificial light.

### Table 2: Coefficient of reflection: walls

<table>
<thead>
<tr>
<th>Material</th>
<th>Coefficient of Reflection</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plaster: cream colour</td>
<td>ρ = 60%</td>
<td>actual state</td>
</tr>
<tr>
<td>Plaster: blue colour</td>
<td>ρ = 35%</td>
<td>new colour</td>
</tr>
</tbody>
</table>

#### 4.2 Lighting

From an energetic point of view, to reduce the installed power and improve the lighting efficiency, avoiding high heat gains from old lighting system, the old luminaries have been improved with efficient reflector so that more light is now directed onto the exhibition space. The use of such efficient features can reduce glare and increase illumination levels, providing required lighting levels using half the number of fixtures. The light design has meant a significant lower energy consumption in addition to, as recent researches have shown, an increasing of exhibition conditions and comfort.

#### 4.3 HVAC

In fact, the climate control inside that ancient historical buildings, is not easy. Such buildings have generally architectural features that are protected by specific regulations. This, on one hand allows collections to be shown in an impressive context, but on the other it implies limited possibility for intervention because those ancient buildings were not originally conceived for exhibition purposes. In such buildings many compromises need to be made also because the installation of HVAC system may be not compatible with the architectural characteristics.

This situation is very common in Italy. This is the case of Bardini museum where rehabilitation interventions are greatly conditioned. The museum was seldom crowded and this reduced the influence of people on the indoor climate could be an opportunity to avoid the use of any artificial system to quickly balance the indoor climate changes. The use of natural ventilation integrated in windows is potentially a good strategy to control indoor climate. The use of night ventilation is also feasible, as inside air speed control is not an issue as there are no visitors inside the museum at night time. This could be a very useful technique during the summer by helping to cool down the building envelope and obtaining the maximum advantage of the thermal mass which is usually a characteristic of ancient buildings. But both visitors and exhibits and staff comfort is required, especially for such kind of exhibits as paintings, water-colours, that are extremely sensitive to little temperature or humidity changes and can fast deteriorate when thermo-hygrometric and lighting indoor parameters aren’t uniform and there is excessive light levels.

#### 4.4 BEMS

So, an HVAC system has been also installed, equipped with thermostatic valves on the distribution system and outdoor air temperature sensors. The HVAC system is operated by an advanced energy management system that include also a smart control for ventilation. This system reduces energy consumption and ensures the maintenance of this
saving: the BMS allows full control and monitoring for all the function of the ventilation system components.

But the building energy management system works not only just to control thermal parameters, ventilation or air quality, but also to regulate the artificial lighting and the radiation control systems, integrating a larger number of sensors for fire alarm, smoke ventilation, control security systems according to the internal requirement, etc.

The basic elements of an intelligent control system are: one or more sensors, that measure the parameters required for the implementation of any required control strategy and a controller that sends appropriate commands to the actuators, once it has processed this received information. The controller will instruct the actuators based on programmed algorithms and in response to the measurements.

In the specific project of Bardini Museum, BMS has been used for regulation of thermo-hygrometric conditions and daylighting control also. The control system for optimised indoor climate for exhibit preventive conservation and people comfort will include:

4.4.1 Temperature and Humidity sensors
that combine previous operational responses and current conditions to determine the optimum time for turning on the heating system in order to reach the desirable indoor temperature at a specific period.

4.4.2 Occupancy sensor:
that can be used to turn the lights off when the space is unoccupied or periodically occupied. We will use the most efficient one, which turn lights off when room is unoccupied and leaves the occupant to turn the lights on if required, eliminating the possibility of the lights coming on by small movements such as wind.

4.4.3 Lighting sensor:
that makes it possible to keep the level of illumination in the room at the design level as daylight varies. It also permits a considerable saving of electricity, longer life for lighting equipment and simple management of reserve lights.

5. CONCLUSIONS

The proposed demonstration building is a representative example of a common type of museum in Italy and therefore it is very suitable to serve as an exemplary pilot project for an historical museum retrofitting.

The aim of the project was to apply appropriate and strategic low energy and sustainable techniques for a better energy retrofitting, without altering historical characters. This project had intended to demonstration that this type of historical building suits very well with the application of sustainable design and energy conservation systems.

Particularly, the objectives of this demonstration were:

- to set a new standard for energy consumption as this type of museum through energy efficient retrofitting
- to enhance indoor environmental conditions and to improve working conditions for staff and visitors
- to minimize the environmental impact of the building
- to reduce the total energy consumption
- to reduce the CO₂ emissions
- a simple payback of eligible installation and design cost less than 15 years.

The final products of this project involve:

- An application of new developed, tested and fully documented measures for retrofitting combining the scientific and technical knowledge in order to improve the energy performance and indoor environment of museum buildings;
- A complete analysis with a specific monitoring of the energy, environmental and economic benefits connected to a direct application of high energy efficiency measures;
- the production of complete data utilisable through an appropriate dissemination activities suitable to provide specific guidance to designers who wish to reduce energy use in existing museums or to refurbish a museum with latest energy saving and environmentally friendly techniques.

The importance of this proposal is to transfer recent E.U research achievements in practical applications: in fact, real scale basis application contributes to the integration of new products and will assist efforts of the European industry in order to commercialise these products and will permit a better penetration of solar and energy efficiency systems and products into the building sector.

Moreover, this application of retrofitting actions foresees some radical interventions in order to ameliorate the building functionality and its energy performance.

The application of an innovative retrofitting design in a real scale basis, linked to the recent scientific and practical achievements, has a good effect because comfort conditions will be greatly improved, energy use for heating as well as for cooling will be largely reduced, and at the same time, the required investment is acceptable.

This demonstration project can provide with a direct guidance complete with architectural and engineering examples for designers and owners. The results of this project will be easily usable by the target audience such as designers looking for ideas, techniques and examples of environmentally friendly ways to refurbish museums buildings. Besides, the application and test of low energy design and technology features require a demonstration action.

6. ACKNOWLEDGEMENT

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