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Enhance Daylight inside museums.
Visual comfort, preventive conservation and energy savings in the EU pilot project: National Etruscan museum “Pompeo Aria”, Marzabotto, Italy.

Angelo Mingozzi, Sergio Bottiglioni

1. National museum P. Aria in Marzabotto: a demonstration project of the EU Project MUSEUMS about energy efficiency and sustainability

The retrofitting and enlargement of the National Etruscan Museum “Pompeo Aria” in Marzabotto, Italy, is one of the demonstration projects of “MUSEUMS” EC FP5 Project [1]. The Project aims to define methods and procedures for an integrated approach to the sustainable design of new or retrofitted museums [2].

The target is to demonstrate that a comprehensive design approach can ensure energy efficiency and sustainability together with the preservation of cultural heritage.

This issue needs a holistic view and the definition of strategies that are both conceptual and based on innovative technologies.

The solutions proposed for the museum are the result of a constant testing and control process which aimed to check design choices, to evaluate alternatives and always verify the fulfilment of initial objectives.

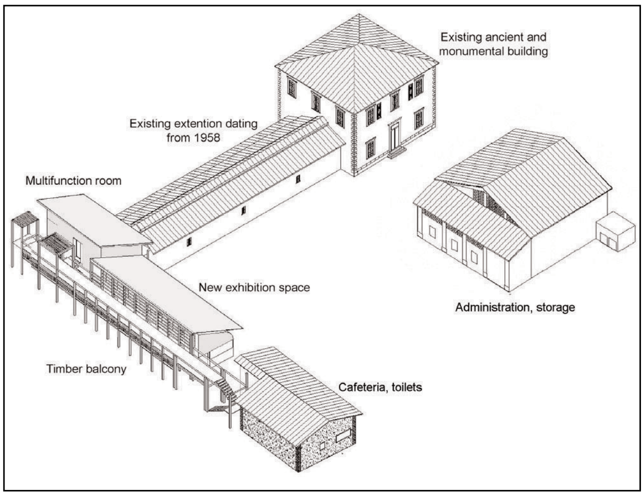
Marzabotto museum “Pompeo Aria” is a significant case study as it is representative of more than 3000 small-middle size museums located all over Italy. The most part of these museums is public property and typically they host exhibits coming from the same site. In many cases their indoor environmental quality, as well as their energy performance, is poor.

The museum is located by an Etruscan settlement of the 6th century B.C., close to Marzabotto (Bologna) and shows exhibits and artefacts found on site during different excavation campaigns. Formerly the museum was composed by a two-story square-based building, made at the end of the 19th century, and two single floor buildings which are later extensions of 1958 and 1979.

A first investigation proved that energy performances and indoor climate control were inadequate; therefore a complete programme of retrofitting and rehabilitation and a long term monitoring have been set up. The project aims to balance active systems with bio-climatic strategies and passive solar techniques to assure the best conditions for people comfort and exhibit preventive conservation together with energy savings [3].

Project objectives are to re-qualify the existing museum and to create more spaces such as a new exhibition hall and a multifunction room built after the demolishment of the storage and boiler rooms.

Retrofitting actions include the complete renewal of the heating system, the improvement of thermal mass and insulation in some existing exhibition spaces; the new constructions are wholly conceived according to general objectives.



Pict. 1: axonometric view of the museum complex, as planned in the new project.

At present only the outdoor timber balcony is not yet installed but will be mounted in the next months. Among different aspects, daylight design has been particularly detailed in order to enhance its use and thus increase indoor quality, meet energy conservation requirements, while keeping under control preventive conservation needs.

2. Daylight in museums: opportunities and risks

The positive effects of daylight on human comfort are known. Considering a space devoted to exhibition, daylight can supply the right amount of light, together with a spectral composition that ensures favourable perception of exhibits details and colours. In the other hand, daylight and artificial light may causes specific conservation problems in Museums by damaging the objects.

This destructive action has been studied since late 19th Century and both visible light and ultra-violet light effects have been investigated.

Light, together with hygro-thermal conditions, is the most important aspect to be controlled in order to promote preventive conservation.

Light influences objects deterioration in different ways [4]: increasing photochemical reactions, whose most evident consequences are the discolouring effect, and an increase of fragility, especially if combined with high temperature. Although reducing the ultra-violet light is somewhat easy because it does not contribute to vision, control of visible light has obvious implications with the overall quality of vision.

One of the most important parameters that evaluate the destructive action of light is the total amount of light received, which can be expressed through the maximum accumulated light exposure on a yearly basis (lux h/year).

As concerns the definition of requirements to prevent light damage, it is common to divide objects into three categories, depending on their sensitivity to light: insensitive, medium sensitive and very sensitive [5]. The following table shows some reference conservation values according to different kind of objectives.

OBJECTS LIGHT SENSITIVITY	MAXIMUM ACCUMULATED LIGHT EXPOSURE (lux h/year)
very sensitive	10.000
medium sensitive	100.000
low sensitive	3.000.000

Char. 1: maximum accumulated light exposure on year basis suggested by the Canadian conservation Institute, Ottawa [6].

The figures in the previous table “should be looked at considering that a full appreciation of colours is not achieved until about 250 lux. Light levels recommended for sensitive

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objects preclude the use of daylight. Some highly controlled daylighting systems (normally skylights) exist to maintain 200 lux on the objects, but an approach based on accumulated light allows a more flexibility to maintain conservation requirements. Some commentators suggested that very sensitive objects, which may have to be lit at 10 lux or below (eg. the Leonardo's cartoon in London's National Gallery), can be viewed at higher levels, but for a restricted time" [7].

More recently CIE Technical Committee 3-22 Museum lighting and protection against radiation damage published guidelines and references to deal with such an important aspect [8].

While in one hand visual comfort asks for daylight, the preservation of our heritage requires a dim environment. These needs are apparently conflicting.

In the framework of Museums Project general targets, the demand for a rational use of energy implied deep investigation of sunlight as a mean to both save energy and increase indoor quality. All the experts agreed on the necessity of carefully evaluate the real conservation requirements, but the solution introducing "by default" dim exhibition spaces was considered an unacceptable shortcut.

In order to manage such complexity and find the "best compromise" a design methodology has been implemented for the simultaneous fulfilment of many objectives: preventive conservation, human comfort, energy saving and environmental impact reduction.

3. A comprehensive approach requires a methodology to define real targets

In order to manage the topic of indoor climate control inside museums through bioclimatic and passive strategies, a comprehensive approach needs to be developed. In the framework of Museums Project a conceptual methodology has been suggested [9]. Such methodology aims to help designer and every member of the cross disciplinary design team to focus on actual environmental needs both for conservation and comfort which are to be related with the building passive aptitude to "mediate" and provide the required conditions. Building and active devices have to work together and to be integrated, both physically and functionally, with special care not to exceed actual needs.

The proposed method focus on the parallelism existing between human comfort and conservation requirements, that allows to break down the problem in simpler steps and to evaluate possible compatibilities.

For each main aspect (thermal, air quality, visual and acoustical) a set of specific requirements can be defined. Some of them concern both humans and exhibits, and some others just exhibits (for example seasonal temperature variation) or just humans (for example acoustic requirements). Requirements are defined in similar ways for exhibits and people. In the first case we start from exhibits classification and in the second case from the activity that has to be performed in each space.

For both we define firstly the quality needs (for preventive conservation or comfort) and then the parametric requirements.

Once the compatibility range is defined, the result should be compared with existing building performances (when retrofitting) or should help to define project targets for new constructions.

The methodology previously mentioned is basically divided into logical steps following the design process:

a. analysis of all the activities taking place in the museum and selection of spaces with similar environmental requirements;
b. definition of human comfort values for each group of spaces;
c. classification of museum exhibits;
d. selection of conservation values from literature or when possible with the help of a conservator;
e. definition of the best microclimate values for preventive conservation and definition of a compatibility range shareable by different categories of exhibits (in show case, room, etc…);
f. comparison between microclimate values for preventive conservation and people comfort (permanent exhibition area) - evaluation of possible compatibility;
g. comparison between compatibility range and monitoring results (only for retrofitting of existing building);
h. definition of retrofitting/design priorities: design scenarios.

Such logical division of the decision process into elementary steps for climate targets definition permits to correctly set real needs. The evaluation of compatibility between human comfort and conservation requirement may lead to different solutions. Objects and people can or cannot share the same space: in some cases it is thus necessary to separate the two microclimates (for example with special climate controlled showcases) and in some other they can stay in the same environment.

The following table shows an extract from the results of the analysis carried out for the museum of Marzabotto. In this project, like in most cases of non-organic exhibits coming from archaeological excavation, the deterioration process to which they've already been exposed has made them mostly insensitive or low sensitive towards climatic actions and generally climate environment suitable for people is satisfactory even for them. Of course some specific attention especially on daily variation for temperature and humidity and UV exposure for lighting has to be considered.

	REQUIREMENTS	*Unit of Meas.*	**Exhibits to be exposed in the same room**		***PEOPLE*** **Comfort parameters**	***POTENTIALLY COMPATIBLE?***		***COMPATIBILITY RANGE*** ***(EXHIBITS/PEOPLE)***
			TERRACOTTA	*COPPER, BRONZE, BRASS, LEAD*		**Yes**	**No**	
Visual/lighting	Illuminance level control	*lux*	$50 < E < 250$ lx	$E < 300$ lx	200 lx $< E < 300$ lx	X		200 lx $< E < 250$ lx
	Maximum yearly exposition control	*lux h / y*	Expo < 80 Mlx h / y	Expo < 5 Mlx h / y	/	X		Expo < 5 Mlx h / y
	U.V. radiation control	*W/lumen*	$UV < 75$ μW/lm	$UV < 75$ μW/lm	/	X		$UV < 75$ μW/lm
	Daylighting control	*lux/lux*	/	/	$DF > 2\%$	X		$DF > 2\%$
	Glare control	/	/	/	$G = 1{,}15$	X		$G = 1{,}15$
	Correlate colour temperature control	*K*	/	/	$3000\,K \leq TCC \leq 4000\,K$	X		$3000\,K \leq TCC \leq 4000\,K$
	Colour rendering control	/	/	/	$80 < Ra < 90$	X		$80 < Ra < 90$

Char. 2: an extract (visual/lighting aspects) from the result of the analysis carried out for an exhibition room of the Museum. Results have then been compared with monitoring of the existing situation and design priorities have been evaluated.

A correct definition of indoor climate values has a main importance for people comfort, exhibit conservation and energy savings. As mentioned, the design strategy requires a comprehensive approach in order to balance the use of passive and active systems. Sometimes an accurate analysis of exhibits and of "museum occupancy model" (number of persons, occupancy pattern, operation, etc.) makes possible to reduce the needs in terms of heating/cooling loads and to dimension the HVAC system without any overestimation.

The methodology previously described (adjusted according to specific needs) has been successfully applied to the different case studies involved in Museums Project, and has driven to different design solutions to overcome the problems and solve specific needs.

4. Objectives and solutions adopted in the project

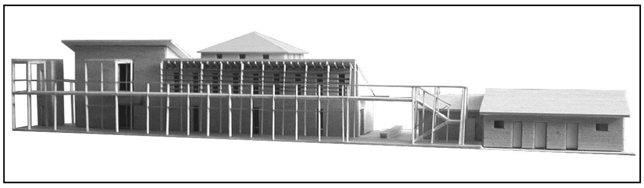
General bioclimatic concepts, as well as specific architectural and technical solutions applied to Marzabotto project are thus the outcome of the previously described methodology, which helped to focus on targets and find best compromises in order to control indoor climate by passive means as much as possible, reducing energy demand.

The extension and retrofitting of the existing museum was based on a sustainable approach aiming to balance biocli-

matic and passive solar techniques with active systems.
As concerns daylighting, the definition of design targets about the extension started from the evaluation of daylight quality in the former museum.
The investigation has shown that overall conditions were inappropriate and, as regrettably often happens in Mediterranean museums, there was not any specific daylighting design.
In the first part of the museum, located inside the historical building, daylight is neglected and existing windows have been blinded. Here the whole space is artificially lit, so that spending much time here gives a bad subjective feeling, sense of fatigue and claustrophobia. The exhibition located in the extension of '70 has a skylight which lets daylight in without control. This creates reflections upon showcases and affects visual comfort.

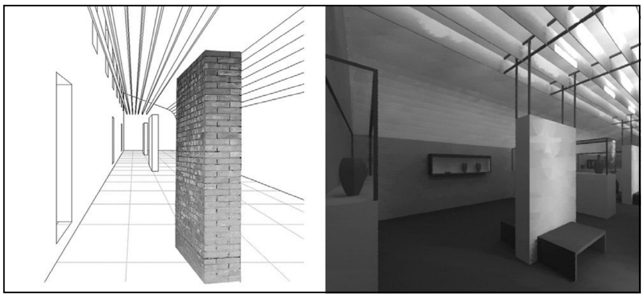
Pict. 2: examples of light neglect in some existing exhibition rooms of the museum: annoying reflections on showcases, on floor and claustrophobic spaces.

Such skylight is also inefficient in controlling thermal loads and overheating during the summer, and high heat losses have been recorded during winter monitoring. The system needs to be completely revised.
As the old exhibition spaces don't allow any view to the exterior, an aim of the new exhibition hall (facing south) is to offer a better relation between indoor and outdoor, in order to reduce "museums fatigue". Moreover that was a great occasion to create a visual relation with the archaeological area.
The southern façade will be protected, all over its length, by a timber balcony integrated with screening equipments to control thermal radiation and daylight.



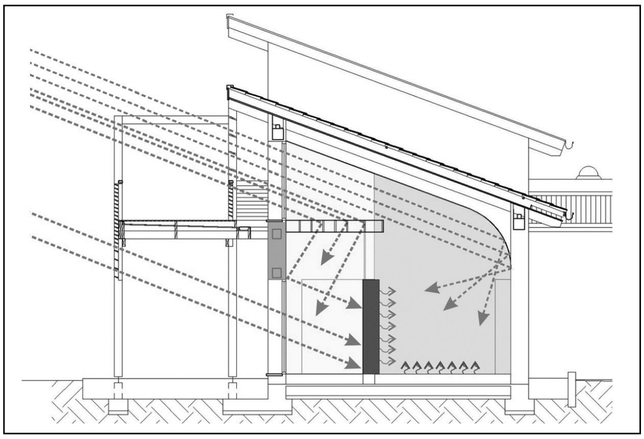
Pict. 3: wooden model replica of southern façade and timber balcony.

Such balcony works also as an exhaustive view-point for the visitor who wants to walk upstairs and have a total perception of the area, while he walks toward the multi-function room placed at the upper level of the corner building. Under the balcony is possible to create a partially protected exhibition space for insensitive exhibits, such as tombstones.
The new hall has thus been divided into two functional spaces: one dedicated to the exhibition and the other serving as passageway and rest area.
For each space, needs and requirements were defined according to previous methodology.
The passageway uses the positive effects of natural light varying in quantity and quality in order to break the monotony and create an emotional dynamic space, from where it is possible to look at the archaeological area.
Exhibition space is separated from walking space by some massive brick walls that screen the light coming from windows and provide high thermal mass for passive summer cooling.



Pict. 4: massive brick walls divide the room into two functional spaces, screen exhibition from direct sunrays and act as thermal masses.

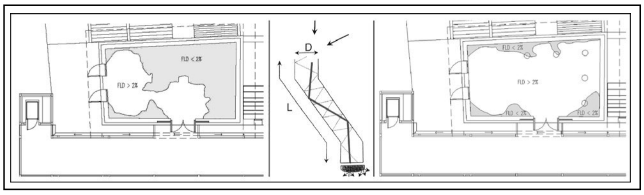
The specific layout of the future exhibition wasn't yet defined, thus only general rules could be stated. Nevertheless the nature of exhibits is known and thus their needs for preventive conservation.
Exhibition space has been conceived aiming to control the amount of daylight and UV radiation, to avoid glare and to create a more uniformly daylit and controlled environment.
Since the new building faces south, in order to enhance passive solar gains all the transparent apertures are located in the south façade, which has a wide area because the single-slope pitched-roof faces north. Vertical glazing on south orientation create a more unstable lit environment if compared to north oriented glazing. Depending on sun rays incoming angles, radiation goes deep inside the building during winter time, while during summer solar rays are externally shaded to prevent overheating. This has been a starting point to specific technical solutions.
The overall system for shading and control daylight is made by a set of external and internal devices. External fixed system of horizontal timber louvers are dimensioned to block sunrays during summer and let them in during winter.



Pict. 5: scheme of how sunlight is reflected and controlled by many devices.

An internal system of lamellas is used to intercept and redirect entering sunrays; the geometry of the indoor lamellas was dimensioned in order to collect and diffuse a larger amount of light to the corridor, where the dynamism is a value, and to reduce the amount of light entering exhibition space.
In order to manage that part of winter sunrays not intercepted by the lamellas, a curved false ceiling together with fabric screens will be installed so to reduce light flux and increase diffusion.
With such devices natural light reaches the exhibition space from the top. This has several advantages: light is more regularly distributed, windows highest luminance is not in the direction of view, and more vertical space is available for exhibition; moreover, thanks to the internal devices ai-

med to diffuse light, veiling reflections from windows are avoided. Upper windows are provided with a UV filters. Such devices is necessary to control their performance during time and continue to evaluate their effectiveness.
The multimedia room located at the first floor will serve for different activities. Side windows provide a non uniform day lit space; in order to integrate daylighting, simulations studied the effect of roof tubular daylight guidance systems [10].

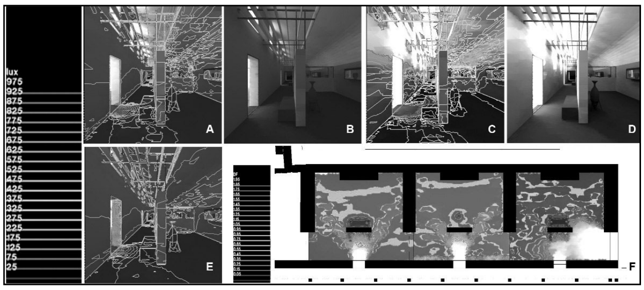


Pict. 6: simulations of Daylight Factor inside the multimedia room, before and after the installation of roof tubular daylighting systems; the simulated daylight guidance system is Solarspot produced by Solar Project S.r.l., Italy.

With such devices a greater uniformity could be obtained, increasing illuminance level in the darkest part of the room.
The artificial lighting system will be designed in order to be integrated with daylighting strategy and ensure electricity consumption reduction.
Artificial light will supply the lack of natural light according to daylight amount and presence of visitors. The ambient lamps will be controlled by illuminance sensors which turn on lights according to daylight availability. These sensors will be installed in locations representative of the task area and the set-points will reference the daylight incident on the floor.
Since the presence of visitors is not continuous and is more intense in some hours and periods of the year, especially as consequence of school visits, infrared sensors will detect people and turn on showcases illumination to give the right amount of light only for the necessary time, in order not to affect the exhibits.
Ambient artificial lighting should be reduced and operate only when daylight is not sufficient because, as simulations show, often the natural amount of light permits to have a good perception of the space and to easily move and see.

5. Control and verification: a fundamental step of the design

To choose among different solutions and verify the choice is a fundamental step of the design. A constant checking of design activity allows to evaluate different options and to meet the specific design objectives.
The bioclimatic design of the new hall required to consider both thermal and daylight issues associated with the system of glazing and shading devices. Thermal performances have been simulated with dynamic tools as ESP-r, while LBL Superlite and Radiance have been employed for daylighting. In order to evaluate the amount of natural light, both overcast sky and clear sky with sun in different seasons have been simulated.
In order to establish if the space has normally a predominantly daylit appearance, the average Daylight Factor has been calculated too.
Such simulations are also used to know levels below which a room should not fall, even when electric lighting is on.
Moreover, some luminance pictures was calculated to simulate a realistic point of view to the daylit space and to find problems due to reflection, glare and other uncomfortable conditions.



Pict. 7: LBL Radiance simulations of light distribution to verify different illuminations in passageway and exhibition room, at 12 o'-clock. A: illuminance levels the 21st June, sunny sky; B: luminance the 21st June, sunny sky; C: illuminance levels the 21st March, sunny sky; D: luminance the 21st March, sunny sky; E: illuminance levels with CIE overcast sky; F: Daylight Factor on floor.

6. Conclusions

The paper aims to enhance the use of daylight inside museums building. Museums become more and more spaces where the original purpose of preserving and showing parts of the human heritage goes side by side with other functions related with culture, education and recreation. All that requires daylight to satisfy visual comfort needs and increase indoor quality.
Because of an approximate design approach, daylight is often neglected and as consequence visitors feel sensation of unpleasant space and fatigue.
To avoid or to reduce daylight is justified by conservation needs which in many cases are approximately defined and not sufficiently investigated. Daylight reduction results in large use of artificial light and increased energy consumption, that causes indoor thermal loads and a major need of AC during cooling season.
A paradoxical issue happens when one cuts off daylight for conservation reasons, but in the other hand the use of artificial lights create a worse problem, because of high illuminance levels falling on art pieces for many hours [11].
The problem has to be treated carefully and it is necessary a wide overview to consider all the advantages and disadvantages related to daylight and find the best compromises. The conceptual method hereby described can be a starting point for better future investigations.

References

[1] The Project “MUSEUMS – Energy and Sustainability in Retrofitted and New Museum Buildings” (contract duration 2000-2004, contract n. Nne5/1999/20), coordinated by Meletitiki Tombazis, Athens, aims to define methods and procedures for an integrated approach to the sustainable design of new or retrofitted museums. The project includes 8 demonstration case studies, located all around Europe. Angelo Mingozzi is the scientific responsible, local coordinator of the cross disciplinary design team of Marzabotto project and leader of the “Horizontal activity” about “indoor climate”. Some more information on the project are available at: http://www.sustainable-european-museums.net/.
Before such Project, the museum has been also the case study of two other research programmes “Retrofitting of Museums for Antiquities in the Mediterranean Countries” - JOULE III Project (JOR3-CT95-0013) and “Guidelines for the design and Retrofitting of Energy Efficient Museums for Antiquities in the Mediterranean Countries”-SAVE II Project (XVII/4.1031/Z/97-086).
[2] An integrated cross disciplinary approach in building design is one of the challenges to promote sustainability in everyday practice. Aiming to find the best procedures, the weak points of the decision making process to develop guidelines the RTD Demonstration project “SHE: Sustainable Housing in Europe” is co-funded under the EC V FP (years 2003-2007). SHE’s main scope is to try to define methodological solutions to renovate the whole building process in order to introduce su-

stainability as an “ordinary” procedure finding the right balance among economic, environmental and social benefits. Results are tested and applied to 200 dwellings of pilot projects located in 4 different countries: Italy, France, Portugal and Denmark.
The authors, as Ricerca & Progetto are partner of the project and act as expert members of the “horizontal activity group” and designers of one of the pilot projects in Italy.
[3] Mingozzi, A., Bottiglioni, S., “National Etruscan museum Pompeo Aria, Marzabotto, Italy: an example of an integrated approach to sustainable museums design”, Proceedings of 21st international PLEA conference, Eindhoven, Netherlands, 19-22 September 2004.
[4] A lot of publications report investigations about preventive conservation and suggest conservation values for the different kind of exhibits. A wide selection of publications and researches can be found in Library and Archive of ICCROM-International Centre for the Study of the Preservation and Restoration of Cultural Property (www.iccrom.org).
[5] According to the deterioration caused by light objects can be divided in: very sensitive, medium sensitive and low/insensitive. Very sensitive objects are for example photographs, works on paper, textiles, natural history exhibits, watercolours, etc…; medium sensitive: oil paintings on canvas, wooden sculptures, bones, ivory, other materials painted or colored,etc.. and low/insensitive: stone sculptures, some ceramics, etc...
[6] J. Tétreault, “Airborne Pollutants in Museums, Galleries and Archives: risk assessment, control strategies and preservation management”, Canadian Conservation Institute, Ottawa, 2003, p. 168.
[7] M. Wilson, “Lighting in Museums - Lighting interventions during the European demonstration project Energy efficiency and sustainability in retrofitted and new museum buildings”, Technical information on the MUSEUMS Project web site (http://www.sustainable-european-museums.net/) and final handbook (that will soon be published).
[8] Publication CIE 157:2004 “Control of Damage to Museum Objects by Optical Radiation”.
The report comprises three parts. The first part reviews the scientific principles that govern the processes of radiation-induced damage to museum objects; the second part reviews current knowledge and recent research to provide a commentary on the efforts of researchers to better understand how these processes may be retarded or eliminated in the museum environment and the final part gives the committee's recommendations for lighting in museums.
[9] A. Mingozzi, S. Bottiglioni, “Standards & Specifications on Indoor Climate”, Technical information on the MUSEUMS Project web site (http://www.sustainable-european-museums.net/) and final handbook (that will soon be published).
[10] Tubular daylight guidance systems are linear devices that channel daylight into the core of a building. They consist of a light transport section with, at the outer end, some device for capturing natural light and, at the inner end, a means of distribution of light within the interior. Guidelines and methods to design, use and evaluate performances of such devices has been recently developed by CIE Technical Committee 3-38 Tubular daylight guidance systems in which the authors are members. Final document will be published in next months.
[11] Eva Balestreri, Marina Vio “illuminazione e conservazione: l’emblematico caso di un museo italiano”, Atti del Convegno Nazionale AIDI 2004, Genova, 15/16 novembre 2004.

(Angelo Mingozzi is the author of paragraphs 1, 2 and 3; Sergio Bottiglioni is the author of par. 4, 5 and 6)