Monitoring and assessment for the sustainable management of historical buildings

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ABSTRACT: Assessment and monitoring actions are integrated as possible strategies for sustainable preservation and Cultural Heritage management. In particular, the indoor environment’s performance assessment is necessary to verify either if the building meets users’ requirements, or further planned actions (refurbishment, new systems installation, etc.) are needed. The Cultural Heritage has strict preservation requirements, but it is necessary to meet the users’ needs in term of environmental quality, safety and management. The paper illustrates a research developed by the CISRiC and the SITI Institute, on behalf of ENEA (Italian National agency for new technologies, Energy and sustainable economic development). The goal is the definition of innovative tools for energy efficiency assessment and monitoring, with the purpose of defining guidelines aimed at improving energy and efficient management of the building-plant system. The case study is the southern wing of the *Villa Reale* in Monza (1777-1780), which represents the high complexity of historical buildings.

1 INTRODUCTION: AIM AND CASE STUDY

Today, the historical material's preservation is not a sufficient condition to the Cultural Heritage safeguard. It represents the history of a territory and it is a fragile and non-renewable resource in a changing world. The social and environmental changes constitute risks to the conservation and the environmental necessities and the user needs are important current issues. Another important problem is the sustainable management in term of financial expense; concerning this, the energy consumption reduction allows to cut also the operating costs. The Cultural Heritage preservation and its security must consider the anthropic hazards and, in particular, the carrying capacity connected to the use, as the environmental loads in relation to the presence of the users and the resulting changes of the climate parameters.

The paper describes a research carried out by a group of the University of Pavia together with the SITI Institute. The work fits in a national program agreement between the Italian Ministry of Economic Development and ENEA and the goal was the definition of guidelines for energy performances improving of historical buildings and for an efficient management of building systems. The multidisciplinary expertise of the team are able to provide the scientific support on some complementary and integrated research lines:

- support to the internal microclimate characterization, in relation to the degradation dynamics of the buildings and any contained furniture;

- support the identification of technological and design solutions for the integration of systems and solutions aimed at energy efficiency and exploitation of renewable energy sources, in case of historical buildings;
- support to the elaboration of indicators to assess the building state in terms of energy efficiency and indoor environment quality.

Foundational assumption of the work is the impossibility of facing a sustainable built heritage preservation without considering the knowledge assessment together with the monitoring. The research included both on theoretical and experimental topics. These ones were focused on the Villa Reale in Monza as experimental case study, because of its exceptional importance and complexity. The results of the research aim to be exportable to other relevant monuments.

The *Villa Reale* was designed by the architect Giuseppe Piermarini (1734-1808) on behalf of the Austrian Empress Maria Theresa, in order to be the residence of her son Ferdinand, Governor of Lombardy. The architect designed a "U" shaped neoclassical style building, considering also the richness of examples as the royal palace of Caserta, designed by Luigi Vanvitelli (1700-1773) with whom Piermarini was trained. After many vicissitudes, when the *Lombardo-Veneto* reign was annexed to the State of Piedmont, the *Villa Reale* became the summer dwelling of the king Umberto I (1844-1900) and some parts of the palace underwent a radical transformation by the restoration of architect Achille Majnoni (1855-1935). After the assassination of Umberto I, the king Vittorio Emanuele III (1869-1947) hasn't wanted to use the *Villa* anymore and, in 1934, a Royal Decree made a gift of a large part of the *Villa* with the municipalities of Monza and Milan. The events of the second post-war caused further spoliations and decay. The southern wing became state heritage, with the advent of the Republic, and the Villa is currently managed by a consortium. The restoration of the nine staterooms of the first main floor started in 2003. Nowadays the main body of the Villa is under restoration and will host exhibitions, congresses, representative offices and international events during the Expo 2015.

2 MONITORING AND PRESERVATION OF HISTORICAL FEATURES

2.1 Adaptive reuse of historical buildings

2.1.1 Energy improvement

The motto "keep safe from harm" is very usual in the field of historical buildings, but the preservation by itself is a necessary but not sufficient condition to a restoration project. It is necessary a sustainable reuse strategy to achieve a long-term result and it is fundamental to take into account the needs of the actual situation. In particular, Cultural Heritage preservation has to be integrated with the energy efficiency needs, which have to be developed with appropriate approaches to the historic features. Energy consumption is moreover problem is connected with the necessity to reduce the not-renewable resources together with the difficult economic management.

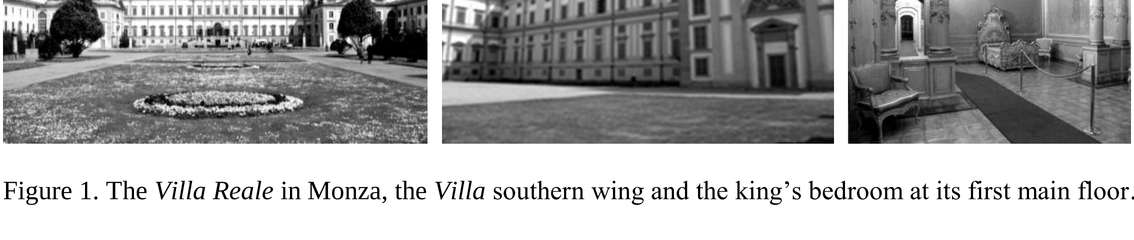

Figure 1. The *Villa Reale* in Monza, the *Villa* southern wing and the king's bedroom at its first main floor.

The need of the greenhouse gas reduction, which are stated by the Kyoto protocol, the conservation of energy resources, the users' comfort and the reduction of the environmental impact of the building life cycle are strategic key words in the modern construction industry. The topic of the sustainable building is present in the European directive 2002/91/CE about the building energy performance; European nations shall provide that the new and the existing buildings satisfy the minimal energy requirements, in terms of effectively quantity of used energy or in terms of energy predicted in relation to the building use.

These considerations are the start point of the research about the case of the *Villa Reale*. At first, the research was based on a recognition of available technological solutions oriented to the integration of energy efficiency systems in the historical building. As range of possible solutions is always different due to building features, its morphology, its materials and content, the second step was the identification of an evaluation method of possible design actions, rather than an exhaustive list of possible solutions. The study identifies the environmental sustainable needs (Environmental quality, Consumption of environmental resources, Environmental loads, Indoor quality, Service quality, Management quality), which are obtained from the assessment classes of the *ITACA protocol* for the assessment of the energy and environmental sustainability of buildings, introduced in Italy in 2004. Each class of environmental needs concern peculiar features of the sustainable planning and everyone has corresponding requirements, which are qualitative or quantitative requirements and which are the conditions to satisfy expected needs. The advantages of the identified design actions must be evaluated in terms of the requirements connected with the classes of environmental needs. In particular, the research developed a system of indicators, which are able to assess the intervention and the monitoring of the indoor environment (paragraph 3). The main classes of indicators are: environmental quality (temperature, relative humidity, gas, light, acoustic comfort), safety (environmental safety, rules observance, cultural value preservation, material safety) and building management (accessibility, orientation, versatility, services and similar ones, easy of clean, easy of management). The environmental conditions are controlled by the monitoring actions. The parameters are different in relation to the materials and the historical features.

2.1.2 Anthropic hazards and assessment of adequate use

Place a new function in an existing building introduces an additional complexity, due to both the necessity to answer the users' needs and restrictions related to historical features. However, the users' needs constitute also some hazards to the safeguard of the historical building. In particular, today, accessibility, security, some services for the users (toilettes, rest stops, shops…) and modern standards in relation to the indoor quality are necessary, but the original plan of the historical buildings hadn't considered these needs. Their introduction may therefore produce heavy changes, which may jeopardize the protection of the historical structure. For this reason, the research stressed the damages connected to the man-made hazards.

The safeguard has to occur on the architectural structures, but also in relation to the contained objects, which may have different microclimatic needs in relation to their materials. Preventive conservation is really important in order to consider main environmental threats, thermo-hygrometric parameters and also plants regulations. It is necessary to understand most relevant threats and most harmful factors. The first main floor of the *Villa Reale* is used as exhibition space and the study considers the risks connected with this function. The rooms are characterized by high-value objects as tapestries (damask, silk, velvet), decorated surfaces (varnish, frescos, stuccos), inlaid woodwork.

The air quality control is particularly significant and it is important to know the damage of the pollutants (sulphur and nitrogen oxides, chlorides, ozone, solar radiation, nitric acid, sulphur acid), in connection to a specific material (discoloration, corrosion, acid attacks, etc,). Not harmful pollutants concentrations could cause irreversible damages with the consequence of leading to carry out expensive restorations. Causes of pollutants are both outdoor (urban traffic, industrial pollution, smokes and particulate) and indoor, as building materials (adhesives, paints, damp walls), plants emissions and, above all, users themselves (visitors, staff, management activities, as people's metabolism, combustion processes, room cleanliness). The research considers the list of the main pollutants damages together with the thermo-hygrometric parameters in relation to the specific material (sources: UNI 10829 and regulations of the Italian Ministry of Culture, 2001). Some of the main hazards are also the light and the Relative Humidity. The users' comfort needs produce the requirements and the performances. This methodological approach is based on the concept of the planning quality control, which means the measure of the level of the compliance of the requirements to the plan performances. When the specific features are set and the classes of environmental needs are defined, it is necessary to compare the possible solutions with the chosen use, which has to be verified and validated through the analysis of the impact that the new use will produce on the existing building.

The indoor microclimate monitoring is essential both before the design action, because of the building performance assessment, the consequent evaluation of the necessary efficiency increase and the reduction of the energy consumption from not-renewable sources, and after the refurbishment with the purpose of assessing the reaching of the planned aims. The monitoring is important during the building use too, because it permits to evaluate the effects of the users' loads in term of thermohygrometric parameters and pollutants concentration.

Table 1. Two example of threats: People and Relative Humidity

Threat	Cause	Damage	Frequent causes	Preventive actions
People	employees, intruders	tears, abrasions, theft	unnecessary manipulation , incorrect handling	education of employees, intrusion protection
	guests	deterioration, cracks, scratches, theft	temperature rise, pollutants, moisture, improper handling of objects	optimization of people's flows, prevention of handle objects
Relative Humidity	high/low relative humidity	mildew, corrosion, embrittlement	change of weather or climate	Thermohygrometric monitoring
			condensation, water infiltrations	active and passive monitoring system of the relative humidity
	quick changes of relative humidity	cracking, wrinkling, deformation	Not adequate aeration, wet cleaning of the floors	ventilation improving
			Superficial condensation, moisture from the ground	actions on building envelop

Table 2. Needs of comfort. Relative Humidity (RH) for exhibition areas (UNI EN 15251)

Building	Category	RH for draft dehumidification (%)	RH for draft humidification (%)
Spaces where the criteria of moisture are imposed for the presence of people	I	50	30
	II	60	25
Special spaces (museums, churches, etc..) which may require other limits	III	70	20
	IV	> 70	< 20

Table 3. Needs of comfort. Medium diurnal light factor (F)

Building field	F_{mid}
Dwellings	0.02
Gyms, canteens	0.02
Stairs, toilets, changing rooms	0.01
Classrooms, laboratories	0.03
Hospitals stay, outpatient, diagnostic spaces	0.03
Subsidized public housing	0.06

General Rules	
F < 0,3 %	insufficient
0,3% < F < 2%	discreet
2% < F < 4%	good
4% < F	excellent

	preservation needs				
	wood flooring, inlays, furniture, structural elements	silk and velvet tapestries	marble and stone	painting on canvas	books and manuscripts
thermal and hygrometric comfort and air quality	RH= 45-60% T= 19°-24° C	RH= 30-50% T= 19°-24° C	RH= 30-60% T= 15°-25° C	RH= 40-55% T= 19°-24° C	RH= 50-60% T= 13°-18° C
visual comfort	E_{max}= 150 lux	E_{max}= 50 lux	E_{max} not relevant	E_{max}= 150 lux	E_{max}= 50 lux
acoustic comfort					

Legend:

Compatibility between preservation requirements and indoor comfort performances

High   Medium   Low

Figure 2. Matrix of assessment needs of preservation and comfort of users, in the case of the "indoor comfort" (E_{max} = maximum illuminance; RH = Relative Humidity; t_{max} = maximum temperature)

2.2 Monitoring Processs

In order to perform a proper environmental monitoring in a historical building, the process has to be divided into five main steps.

At the beginning, a site visit needs to be carried out to verify the building characteristics, the systems characteristics and operation, the artworks characteristics and the building use (visitors, workers, etc.). The second step is a strict interaction with the building managers and people responsible for artworks to identify the conservation requirements (e.g. presence of fragile artworks). Moreover, information about materials are useful to determine the ranges of acceptability for the monitored parameters (temperature, relative humidity, etc,) and the related maximum allowable variation (hourly, daily or seasonal). Typically, regulations provide such limits, but specific limits can be identified depending on the conservation of the artwork.

After the limits are defined, the monitoring equipment need to be chosen, guaranteeing the performance level required. The selection process involves the choice of the monitoring type (datalogger, sensor network, etc.), the number of devices, their position and the sampling frequency. A complete environmental evaluation should last more than a year in order to evaluate the thermo-hygrometric trend in all seasons. When the selection process is terminated, the system can be installed and the monitoring can start.

Periodically, a report is generated with representations of trends, statistic data elaborations and a punctual analysis of possible anomalies in artworks conservation conditions.

3 PERFORMANCE INDICATOR FRAMEWORK

3.1 Why a Performance Indicator Framework?

The monitoring process is useful strategy to identify critical issues in the management of a cultural and historical building and to promptly react if some problems are detected. However, to ensure a high environmental quality for both people and artworks, a proper indicator framework needs to be defined, providing a global overview on the building.

Several approaches can be considered. One of the most promising is represented by the KIPI (Key Indoor Performance Indicators) Framework, developed during European project PERFECTION. The KIPI framework evaluates the indoor environment taking into account various aspects: health and comfort (assessing how the indoor environment is healthy and comfortable for people inside the building), safety and security (assessing how the building guarantees safety and security for people and objects), usability and positive stimulation (assessing the easiness of use of the building and positive feelings by the people) and adaptability and serviceability (assessing if the building guarantees adaptability to different activities and good maintenance).

3.2 Indicator Definition

The PERFECTION KIPI Framework was developed for a general building type, thus it has to be adapted to the specific context of an historical building. As a consequence a new indicator set has been defined. The four KIPI categories are rearranged into three ones. The categories in the new indicator framework can be summarized as:

- Environmental Quality. The first category includes all the parameters related to air quality and comfort for both people and artworks. The specific indicators for this category are: temperature, relative humidity, presence of noxious gases, lighting, acoustic comfort.

- Safety. The second category refers to the all the aspects that make the indoor environment safe, considering the adequate protection of the valuable objects and artworks, the compliance with regulations, and security issues against thefts and vandalism. The specific indicators for this category are: environmental safety, compliance with regulations, cultural value protection, security.
- Building Management. The third category refers to the managing issues that could ease people access to the building as well as maintenance aspects. The specific indicators for this category are: accessibility, way finding, versatility, services, cleanliness and maintainability.

The indicator framework is completed with two more indicator, specifically dealing with energy issues (building energy footprint and energy efficiency improvement level). These two indicators can be evaluated through proper simulation software aiming at calculating the energy required by a building to meet the goals set by managers.

The defined indicator set was tested and validated on the *Villa Reale* of Monza, through a qualitative assessment based on site visits and on the preliminary data coming from some preliminary monitoring data collections. Upon the validation process, each indicator has been provided with a five level scale, aiming to help final users to perform a correct indoor environment quality assessment.

The assessment results may be used to identify the priorities of intervention in the building to improve indoor environment performance. Moreover, a global evaluation allows to identify the possible impact of a chosen solution on the whole indoor environment even prior to its adoption on the real case, helping building managers in the decision making process.

4 CONCLUSIONS

The research stressed some multidisciplinary aspects, strictly connected with theoretical and operational aspects. The results achieved may demonstrate its relevance in the general scenario of wide spectrum energy-oriented strategies for sustainable preservation and valorisation of cultural heritage.

The research could be further deepened at least along three different paths:

- an enhanced perspective on different classes of technological elements of the building envelope, such as facades and transparent elements, in order to test and verify the applicability of a wider spectrum of materials and technologies;
- the experimentation of the whole suggested method to different case-studies may guarantee the opportunity to obtain a higher level of reliability and comparability of the results;
- the integration of financial evaluation of the suggested technical solutions may guarantee a more sophisticated level of comparison between different solutions, both in terms of start up and mid-term management costs.

A further development direction, under evaluation in other researches nowadays undergoing in the laboratory is focused on predictive impact evaluation tools to determine the “adequacy” between a function and an historical building, in order to minimize the necessary transformations. The results of this further approach could be linked and integrated with energy-oriented restoration, in a more holistic approach to sustainable restoration.

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