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Italian guidelines for energy performance of cultural heritage and historical buildings: the case study of the Sassi of Matera

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Abstract

The Sassi of Matera are a unique example in the world of rock settlements, developed from natural caves carved into the rock and molded into increasingly complex structures inside two large natural amphitheaters. Research focuses on the compatibility of the energy efficiency measures applied in Sassi buildings with the recent MiBACT guidelines on "Energy efficiency improvements in cultural heritage" and AiCARR guidelines on "Energy efficiency of historical buildings". The paper aims to analyze energy and environmental performance of different building typologies and monuments of the Sassi site.

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1. Introduction

Energy efficiency improvement is one of the main measures promoted by the Kyoto Protocol. In this direction, several European Directives have been encouraged for the development of renewable energy sources and implementation of energy efficiency, such as Directive 2009/28/EC and Directive 2010/31/EU [1, 2].

In Italy, the recent renovation of the Legislative Decree 19 August 2005, n. 192 "Implementation of Directive 2002/91/EC on the energy performance of buildings", operated by Law 90/2013, excludes its application to cultural

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heritage when the observance of requirements imply a substantial alteration of their character or appearance, with particular reference to historical profiles and artistic landscapes [3].

In June 2015, three important measures have also been issued in order to take an important step towards the Nearly Zero Energy Buildings. The first decree refers to the new method for calculating the energy performance and the new minimum efficiency requirements for new buildings and those undergoing renovation [4]. A second decree is aimed at adapting technical report schemes of the project to the new regulatory framework, depending on the different types of works: new buildings, major renovations, energy retrofits [5]. With the third decree, finally, the guidelines for the certification of the energy performance of buildings (EPA) have been updated [6]. These decrees do not introduce innovations regarding the respect of the energy requirements of historic buildings.

On 29 October, 2015, the Ministry of Cultural Heritage and Activities and Tourism (Italy) published specific guidelines for energy performance of cultural heritage [7]. These guidelines provide guidance for the evaluation and improvement of the energy performance of the protected cultural heritage, with reference to the Italian laws on savings and energy efficiency of buildings.

As stated in the Italian guidelines, the energy saving related to the reduction of fuel consumption and of atmospheric emissions of pollutants, is a priority for the preservation of the environment.

In recent years, moreover, the reduction of public spending makes it necessary to reduce energy costs incurred for the running of properties managed. For this reason the knowledge of energy and environmental capacity of historical buildings is important to preserve not only quality and comfort of indoor environments but also to adopt the best intervention strategies for improving energy performance.

To attribute an objective judgment to the environmental quality one should know the physical parameters that influence comfort, energy consumption of a building and healthiness of the environment.

In the evaluation of energy performance, a number of parameters must be taken into account:

- climatic aspects of the locality;
- level of thermal insulation;
- existence of its own energy generation systems;
- technical characteristics and installation of the plants;
- microclimate of indoor environments.

The overall energy performance of the building is expressed through the global energy performance index EP_{gl} (1), which takes into account the non-renewable primary energy demand for winter heating and summer air-conditioning ($EP_{H,nren}$ and $EP_{C,nren}$), for the production of domestic hot water ($EP_{W,nren}$), ventilation ($EP_{V,nren}$) and, in the case of the non-residential sector, for artificial lighting ($EP_{L,nren}$) and for the transport of persons or things ($EP_{T,nren}$).

$$EP_{gl,nren} = EP_{H,nren} + EP_{C,nren} + EP_{W,nren} + EP_{V,nren} + EP_{L,nren} + EP_{R,nren} \quad (1)$$

To determine the building energy class, the EPA preparation is performed as follows:

- determining the value $EP_{gl,nren,ref,standards}$ (2019/21), which is the index of non-renewable global energy performance for a referred building according to [4];
- calculating the value of $EP_{gl,\ nren}$ for the building and its energy class as identified in the table 2 of Annex 1. Cap. 5 of [4].

It must perform the assessment of the energy performance ante and post-operam.

1. Italian guidelines for energy performance of cultural heritage

One of the essential measures, highlighted by MiBACT guidelines, is to ensure the Indoor Environmental Quality improvement for historical architecture in order to preserve their identity and cultural heritage.

The current standards of comfort, established by UNI EN 15251:2008, have changed as to the time of old construction, so it will be important to consider the current parameters of habitability, which refers to different classes of environmental comfort such as indoor air quality, thermo-hygrometric, lighting and acoustic comfort [8].

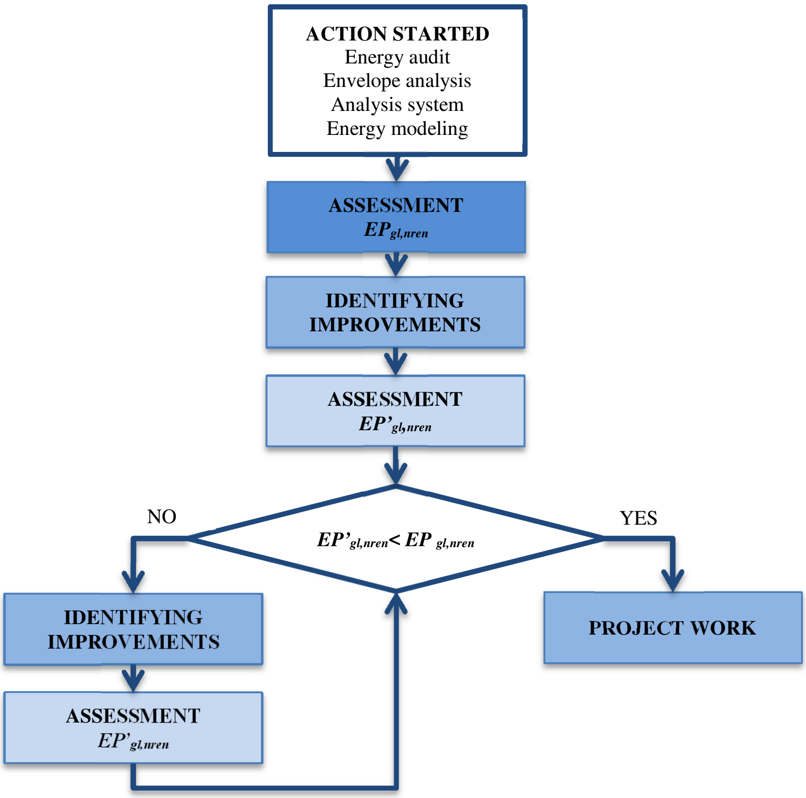

Fig. 1. Flow chart of energy efficiency improvement [9]

The Italian guidelines suggest that, first of all, the analysis of the technical-construction features of historical buildings with the historical interpretation and geometric survey is necessary.

From an operational point of view, the best configuration is the critical integration of various detection methodologies, both direct and indirect (photogrammetry, stereo-photogrammetry, laser scanning). These methodologies might be accompanied by a detailed topographical classification of building and supported by a detailed photographic documentation, which also extends to the environment, indicating the shooting points.

To improve IEQ (Indoor Environmental Quality) Italian guidelines suggest to act on the envelope or on the system. The interventions on the envelope essentially consist in thermal insulation of opaque walls, the replacement of windows and screens. All these interventions act primarily on the inner surface of the walls and then on the mean radiant temperature; consequently they vary the operating temperatures that are perceived by the people exposed to the environment, influencing the feeling of comfort.

Regarding system plants, some historic buildings are generally equipped with obsolete plants that could be as evidence of the past and as such have a historical interest, so they must be carefully recovered, valued and, if possible, made accessible. The Italian guidelines do not suggest measures regarding plants solutions and so the publication of specific guidelines as the type of plant systems compatible with historical building, it is necessary.

The preparation of an optimal energy audit requires the knowledge of a range of relevant information to the system and its features. To do this, at first it is necessary to identify the functions that the architectural and technological systems must satisfy. This can range from climate control to a microclimate one if frescos are housed, to prevent rising moisture in the presence of ground water or underground scattered waters.

The energy audit of a historic building is not a simple process. To collect and organize data can be very useful, for the practitioner, to have cards and protocols to guide him or her in this task. One of the obstacles in old buildings is the lack of adequate plans and sections, together with the lack of knowledge of materials and its stratigraphy, that could be determine by intrusive or non-destructive methods, such as endoscopic techniques or infrared thermography.

Fig. 1 shows a flow cart with steps to improve energy efficiency, proposed by AiCARR guidelines for Energy efficiency of Historical Buildings [9].

For historic buildings, often, the respect of the minimum standards is impossible to obtain because of limitations in actions for the protection of historical heritage. You can implement only the improvement of the energy performance compared to the current one.

2. Thermal properties of construction materials in the complex of Sassi

The Sassi of Matera is among the oldest sites in the world that proves the continued presence of man from the Paleolithic to the present. It is characterized by the presence of an urban area modeled entirely in calcarenite sandstone (tufa stone) that, at times, was excavated and shaped to make the hypogean rooms and, sometimes, assembled by overlapping square blocks to create the built environment (Fig.2).

Fig. 2. The site of Sassi.

Studies on the evaluation of the energy performance of vernacular buildings of the Sassi have shown the excellent energy behavior of these structures [10]. The site was investigating both by non-destructive measurements in situ and laboratory tests.

Measurements in situ, realized from June to July 2007 with maximum values of indoor–outdoor temperature difference, were made on a 48 cm thick wall of blocks. The measurement campaign of the materials shows a cyclical trend of external surface temperature of the masonry for the whole measurement period with values between 40° and 20°C, while the inside surface temperature was constant at around 20°C.

This result shows a very good thermal performance of the monitored masonry in dynamic conditions. The high thermal mass annulled the climatic variations of the external environment.

Table 1 shows the average thermal properties obtained by measures campaign.

Table 1. Thermal properties of calcareous sandstone of Matera

Conductivity λ W/mK	Diffusivity $\alpha\ 10^6\ m^2/s$	Volumetric thermal capacity $\rho c 10^{-6}\ J/m^3K$	Mean temperature T_m [°C]	Density $\rho\ m^3$
0.642	0.437	1.448	25.40	1547

A further analysis was carried out to estimate the thermal mass property of the previously described masonries. Through the calculation method complying with the UNI EN ISO 13786 [11], it was possible to describe the thermal behavior of the masonries under time-variable boundary conditions, that is, under a sinusoidal variation of the thermal flow and temperature on the inside-outside surfaces. The thermal dynamic properties for a 0,5 m wall, very frequently in the Sassi buildings, are shown in Table 2.

Table 2. Thermal properties complying with UNI EN ISO 13786

Masonry in calcareous sandstone	
Thermal transmittance	1.108 W/m^2K
Periodic thermal transmittance	0.093 W/m^2K
Decrement factor	0.084
Time lag	15.7 h

3. Indoor environmental quality of the Sassi environments with dynamic simulation

The Italian guideline highlights the importance to guarantee the environmental quality and comfort of the individual. Environmental comfort was calculated applying UNI EN ISO 7730, which consider three classes of comfort, in function of the value of PMV (Predicted Mean Vote) which is correlated to PPD index (Predicted Percentage of Dissatisfied) (Table 3).

The PMV is expressed as a function of six parameters, of which four are objective (air temperature, partial steam pressure, relative air velocity, mean radiant temperature) and two subjective (energy metabolism and clothing insulation).

Table 3 - Global thermal comfort classes according to UNI EN ISO 7730

Quantity	Condition		
	Class A	Class B	Class C
PMV	-0,20 ÷ 0,20	-0,50 ÷ 0,50	-0,70 ÷ 0,70
PPD	<6%	<10%	<15%

The comfort analysis used is the Fanger Comfort Analysis (1970). His analysis indicated that the sensation of thermal comfort was most significantly determined by narrow ranges of skin temperature and sweat evaporation rate, depending on activity level.

The analysis of the indoor environment allowed to calculate the comfort indexes (Fanger indices PMV and PPD), with a mathematic method applying experimental-empirical formulas (2):

$$PMV = (0{,}303^{-0{,}036M} + 0{,}0275)\,BT \qquad (2)$$

Where:

BT is the thermal balance of human body and it is a function of heat flow of metabolism produced by the body, convective heat flow, radiative heat flow and heat flow by sweat evaporation.

When BT=0 we are in homothermy conditions (comfort).

This value is obtained with dynamic simulation through the software DesignBuilder/EnergyPlus.

The main problem of an energy analysis of existing buildings is given by the poor availability and reliability of data concerning the parameters essential for the evaluation of their performance, such as, for example, the thermal transmittance of the walls and the performance of the plants.

Building performance evaluation, useful for qualification and energy certification, was conducted through the calculation in dynamic and steady state, using existing software, such as Mc4 and Energy Plus.

The use of methods of calculation in dynamic state is essential in the case of massive structures with high thermal inertia because they are the only ones that are able to predict with some precision the energy needs in the cooling period.

The dynamic analysis allows you to more accurately determine the energy requirements useful in winter, when it is necessary to achieve 20 °C for indoor air. For cooling, the steady method returns higher values, as it does not take sufficient account of the high thermal inertia of the studied building envelopes.

In the evaluation of thermo-hygrometric comfort, the synergy of the effect of the external climate, the building structures and the technological systems has to be taken into account. In particular, masonry microclimate and hygrometric content are significant parameters for the conservation of works of art and cultural heritage, in particular when there are mural frescos and rocky-carved churches.

The studies conducted [12] on a rocky-carved church of the Sassi District dated 1583, St. Mary of the Palomba, and on the Cathedral of Matera, show the causes of deterioration of frescos due to the high humidity rate and water infiltration. These phenomena lead to the formation of superficial erosion and re-carbonation areas with the result of a marked deterioration of frescos and color fading (Fig. 3).

Fig. 3. The altar of St. Mary of Palomba Church and the frescos of Madonna Odigitria (XIII – XIV sec.).

Measures carried out for these structures show the average temperature equal to 8,9°C and the average humidity equal to 80,8%. These values are far from the standard of conservation of frescos (environmental temperature between 10°C to 24°C and relative humidity between 55% to 65%).

The environmental conditions that cause these phenomena are the insufficient exchange of air due to the thickness of the masonry that produces a remarkable thermal inertia.

Studies conduct by [13], on different structures of Sassi site, after a requalification of system plants, have returned PMV values between -0.2 and 1.0 and PPD values of below 10%. The calculation was performed assuming a clothing resistance typical of the season (0.45 clo for summer and 0.9 clo for winter) and a metabolic activity of 1.0 MET (resting activity). The thermal comfort was analyzed [14], even for the Cathedral of Matera. In this case, the analysis of microclimatic features was carried out by a multi-channel control unit through five measure points (wall, floor, left column, right column and central zone), after a requalification of a system plant with the use of radiant heating plant floor.

The values obtained, with T=18°C, RH=54%,V_{air}=1 m/s and people with sedentary activity and with high thermal resistance of clothing, are PMV=0.25 and PPD=5.3%, values very close to those ideals of PMV=0 and PPD=5%, which correspond to thermal neutrality. We can conclude that these structures maintain their internal conditions at a relatively good level of comfort and are according to the standard of conservation of frescos, with only a slightly lower temperature for metals.

4. Intervention strategies for historical buildings with massive structure

In the historical buildings of the Sassi, the intervention must be carefully analyzed because of its historical and architectural importance. Often act on the envelope is really difficult because of different limitations, so it is possible to act only on plant system.

Especially in the rocky churches of the Sassi of Matera, the measures to be taken to improve the state of conservation of the environments, where several artworks are present, and consequently, also to decrease the heat loss, could be reduced to simple measures, such as:

- periodic maintenance of windows and doors to improve their functionalities;
- mounting of tents and films to the windows to filter the sunlight;
- use of revolving doors for the optimization of the outside-air trade for the benefit of the microclimate and the air quality of the environments.

Another important intervention is the use of air handling units (AHU) in order to control temperature, relative humidity and to promote energy savings. Often, this kind of massive structure is characterized by a high humidity content of walls, so their indoor environmental quality is compromised.

We have already described in the preceding paragraph the positive performance in the Cathedral of Matera of the heating radiant floor system, with respect to thermal comfort and the maintenance of artworks in a good state of conservation. The system used has some other advantages as the lack of pollutant production and visual impact and the reduced cost of energy compared to other low temperature systems, such as electrical ones.

To improve the energy performance, it is possible to use the following actions:

- installation of internal insulation through the use of aerogel (2 cm thick): an extremely innovative insulating material characterized by a thermal conductivity around 0,013 W/m K;
- installation of windows with double or triple low-emissivity glass, with cavity filled with inert gas and wooden frame with finishes and color compatible with those of the opaque walls;
- introduction of condensing boilers (heating only) and reversible heat pumps (heating and cooling), making up a system to renewable energy sources, because they exploit the free heat energy contained in the air, soil or water;
- creation of a ventilated air space under the floor;
- adequate room ventilation
- installation of a radiating heating system under the floor. It is useful even in the summer and spring when the condensation is high. The heat, in fact, reduces cooling stagnation and saturation of air temperature and reduces the relative humidity with the same vapour content.

These actions are simulated with Energy Plus dynamic software.

The insulation application of 2 cm of aerogel (or equivalent insulation) reduces the average transmittance of the walls at a value comprised between 30% and 50% of the initial one, allowing good reduction of the $EP_{gl,\,nren}$ index. This result is optimal in the winter because it definitely reduces the heating energy needs, while in summer the situation is more complex because the isolation reduces the positive contribution of night-time heat loss to the outside.

Finally with the use of the heat pump we can achieve a decrease of $EP_{gl,nren}$ index around 28% in excavated buildings and around 52% in the other cases.

In environments with very high percentage of excavated spaces, characterized by a high relative humidity, assuming an increase of air changes of 0,3 ac/h at 2 ac/h, the heating energy requirement may even triple than the standard one. This shows that, especially for the underground rooms of the Sassi of Matera, the reduction of energy requirements is not always possible since the priority is to ensure the thermal comfort in the room.

With these different strategies the excavated structures can maintain their internal conditions at a relatively good level of comfort.

5. Conclusion

An interesting consideration is that these buildings are able to reduce the temperature oscillations of the external environment as a result of their high thermal mass, so they could be considered as bioclimatic. Regarding the monuments, as the Cathedral of Matera, the evaluation of the indoor microclimate during and after the restoration works shows excellent results and ensures the optimal preservation of artistic heritage from the thermo-hygrometric point of view. This plant solution (installation of floor heating system) follows the Italian guidelines because this type low temperature system allows high energy savings as it enables the use of combustion systems with high-efficiency (condensing boilers) and/or renewable energy installations (heat pumps, solar thermal collectors).

Even the use of insulation materials, such as aerogel, follows the action proposed by Italian guidelines.

However, these structures, once restored and in a condition of normal use, give indoor comfort within the limits of thermo-hygrometric standards established by indices as the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD).The observed and calculated thermo-hygrometric parameters (T=18 °C RH=54%, PMV= 0,25, PPD = 5.3%) make thermal comfort fully acceptable .

A thorough knowledge of historical heritage and energy performance of the Sassi buildings is a strategy indicated by Italian guidelines in order to preserve the identity of their inhabitants. So it is necessary to conduct a complete mapping of the entire heritage of this city and develop specific guidelines which combine technical and economic feasibility, appropriate landscaping and architectural integration and environmental sustainability within a proper building lifecycle.

The evaluated intervention strategies are extended to all possible cases, although limited to only those elements considerable in the cases analyzed: housing, fixtures and heating systems (combined or not with natural ventilation).

The examined historical buildings require use of energy for heating, but little or almost no energy for cooling thanks to the high thermal inertia. We can conclude stating that the Sassi district is therefore characterized by settlements to "nearly zero energy" at least as regards cooling.

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