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# Built Cultural Heritage and Energy Efficiency. The Sicily Case: Pros and Cons of an Innovative Experience

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# Built Cultural Heritage and Energy Efficiency. The Sicily Case: Pros and Cons of an Innovative Experience

**A Buda[1*], V Pracchi[1] and R Sannasardo[2]**

[1]ABC Department, Politecnico di Milano, 32 Piazza Leonardo, Milan, 20133, Italy

[2]Energy Department, Sicilian Region, 36 Viale Campania, Palermo, 90144, Italy

*alessia.buda@polimi.it

**Abstract.** The paper aims to present a study carried out within the Regional Operational Program - European Regional Development Fund 2014/2020 financing project for the efficiency improvement of 106 public heritage, owned by the Sicily Region. 38 case studies of this stock have been selected, having different uses (museum, library, office, etc.), typology and construction period, shifting from XI to XX century buildings. The sample heterogeneity gives in fact a large-scale overview on the Mediterranean heritage, allowing to assess the efficacy of energy policies (at Regional level) and to suggest feasible retrofit solutions for historic public buildings. Weak and strength points of each case are highlighted as from both an energy audit (based on bills and simulated energy performance data) and an on-field survey in a comparison. The inclusion of stakeholders' interviews in the walk-through investigation has clarified the efficacy of building and plants management. Finally, as tangible results, it is suggested to consider retrofit low-impact interventions accordingly to the building microclimate, as well as objects and users' needs, as a win-win strategy.

## 1. Introduction

In the last decade European and national policies have set ambitious goals to reduce energy needs and emissions (EPBD 2010/31/EC et seq.), boosting the reduction of $CO_2$ emissions, the rise of the share of renewable sources and the retrofitting of existing buildings. Attention has been paid also to the public dwellings (2012/27/EC Directive), asking the public Administrations to improve at least the 3% of the entire stock each year to become retrofit best practices towards nZEB values [1]. In this context, it is necessary to pay special attention to the historic buildings (accounting for nearly one quarter of the European constructions) [2].

While energy legislation tends to solve the conflict between conservation and performance requirements with the possibility of excluding historic buildings under specific conditions, scientific and public sector are trying to define how preservation and energy efficiency could find virtuous synthesis for an efficient use through improvement actions. The concept of 'improvement', introduced firstly in the field of structural safety and accessibility, is spreading to energy efficiency, though in the complex legal framework that is still distinguishing between listed and non-listed buildings [3].

As proof of this trend we find the European standard EN 16883:2017 [4] and, at national level, the "Guide line for the improvement of energy efficiency in Cultural heritage", issued by the Italian CH Ministry [5], in cooperation with the Italian Association Air Conditioning, Heating and Cooling (AiCARR), along with a growing scientific literature on the subject. In this research field, the need of adopting a multidisciplinary approach to the preservation of architectural heritage is clearly recognized by experts [6][7][8][9], but it is not yet sufficiently widespread. A cross fertilization among diverse field of knowledge is necessary to: recognize all different constructive phases, techniques, materials and their conservation state; to monitor the microclimate for evaluating comfort conditions for users and objects; to analyze the consumptions and the set of installation; to involve the building users. This provides the necessary competences for a commensurate type of intervention, meaning able to balance different needs between preservation and – in this case – energy efficiency [10].

Starting from this foreword, the article aims to present a study carried out within the Regional Operational Program - European Regional Development Fund 2014/2020 [11], a financing program for the efficiency improvement of 106 public heritage properties of the Cultural Heritage Department of the Sicily Region[1]. Among the priority axes, there's a specific one concerning sustainable energy and quality of life, fostering eco-efficiency and reduction of primary energy consumptions of the building stock, particularly in public sector. In fact, public heritage serves as good example for the energy improvement, becoming activator of process in territorial development, factor of sustainable development intertwined with an innovation process of cooperation between several actors [12].

Moreover, public assets often have different needs, due their different function (sometimes variable over time) and form of users (direct - such as the visitors of a museum, or indirect - such as heritage officers). For this reason, also operating costs are different: an 8% of costs in the public sector is estimated dependent on operating incorrect practices very difficult to control [8].

In addition, it must be underlined that Mediterranean climate has different problematic in comparison with the temperate and north European one, more studied. Hence, the balance between energy refurbishment measures and heritage preservation is a topic that cannot be ignored. Besides the choice of retrofit interventions, it becomes precondition to understand building needs and thermal behavior with the resulting of a better indoor climate conditions, to the allowed extent under preservation needs.

## 2. Case studies categorization and selection

The first step of the 106-case studies analysis was the identification and collection of available data. Energy audits, carried out previously by the Sicily Region, were the starting point necessary to define possible actions in every site. For each case study a recognition of other useful data has been done, adding knowledge on the state of preservation, the indoor climate conditions and requirements for preventive conservation strategies. Other documents on legal constraints, restoration works, etc. have been found from regional and national archives.

Cases have been classified according to their climate zone and function (church, museum, house-museum, office, monumental building, archeological site and library). For buildings that would not fit into the given categories, the classification 'multiple use' was introduced. These 7 categories reflect different problematics in association with use, protection needs and technical equipment.

At the end we selected 38 cases, among the ones including all needed data: some were identified as representative of the category; some others have been chosen to understand problems related to special conditions (e.g building without plants, building with decay problems, mixed construction, etc.).

Cases were classified by function and climatic zone to be comparable, taking in consideration conveniently constructive and typological differences. The variability of the considered examples can be considered as an advantage, allowing to have a wide overview on the topic issues.

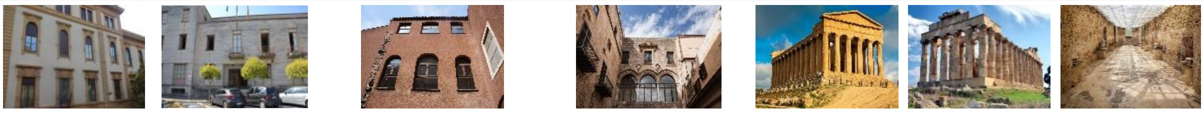
After that, we collected all data to compare them systematically, in order to obtain consumption profiles, incidence rates of consumption type, hourly variation of the building use and assessment of the current management costs (Figure 1.).

The analysis has been accompanied by the inspection of the chosen sites. Also interviews to the end users were carried on in this phase, to understand the real needs and the transformations occurred in the past to the buildings. The combination of quantitative and qualitative data allowed to evaluate,

[1] The ROP is the document defining strategies and interventions to support competitiveness and attractiveness of the regional system towards a sustainable development according to the European 2020 strategy (UE Regulation n. 1301/2013 and n. 1303/2013, undertaken with the Regional Decision n. 267 of November 10th 2015).

with a different level of appropriateness not only related to energy savings but also respect towards the heritage values, the interventions already proposed in the audit phase.

**Table 1.** 38 selected case studies.

| LIBRARY | | | CLOISTER | | HOUSE- MUSEUM | | |
|---|---|---|---|---|---|---|---|
| XVIII century BUILDING - CLIMATE ZONE B | | | CLOISTER XI cent. - CLIMATE ZONE B | | XVIII-XIX cent HOUSE WITH FURNITURES - CLIMATE ZONE B | | |
|  | | | | | | | |
| Regional Library of Catania | Longo Regional Library | Regional Library | Magione's Cloister | Cloister of S. G. degli Eremiti | Pirandello's House | Palazzo Mirto XVIII c | Verga's House XVIII c |
| 1753 - Catania (B) | 1731 - Messina (B) | 1782 - Palermo (B) | XI cent-Palermo (B) | XI cent-Palermo (B) | XIX - Agrigento (B) | Palermo (B) | Catania (B) |
| MUSEUM | | | | | | | |
| XIII-XIX century BUILDING - CLIMATE ZONE B | | | | | | | |
|  | | | | | | | |
| Palazzo Bellomo Gallery | Palazzo Abatellis | Pepoli Museum | Archeol. Eolie Museum | Salinas Archeol. Museum | Antiquarium D. Ryolo | Ancient Theatre Museum | Palazzo Riso Art Museum |
| XIII c. Siracusa (B) | XV - Palermo (B) | XV c. Trapani (B) | XVI c-30s - Lipari (B) | XVI c. Palermo (B) | XVI c. Milazzo (B) | XVII c. Catania (B) | XVIII c - Palermo (B) |
| XIII-XIX century BUILDING OTHER CLIMATE ZONE | | XIX century RURAL BUILDING | | XX cent. BUILDING CLIMATE ZONE B | | | XX c. OTHER CLIMATE ZONE |
|  | | | | | | | |
| Museum of Enna | Aidone Museum | Baglio Anselmi Museum | Museum of Kamarina | Griffo Archeol. Museum | Museum of Messina | Orsi Archeol. Museum | Museum of Caltanissetta |
| XVIII c. Enna (E) | XVII c. Aidone (D) | XIX c. - Marsala (B) | XIX c. Scoglitti (C) | XX c. -Agrigento (B) | XX c. -Messina (B) | XX c. -Siracusa (B) | XX c-Caltanissetta.(D) |
| OFFICE | | | | | | | |
| ANCIENT MONUMENTAL BUILDING (XIII-XIX century) - CLIMATE ZONE B | | | | | | | |
|  | | | | | | | |
| Superintendence of Sea | Superintendence of Enna | Palazzo Fontana | Palazzo Milo | Superintendence of Agrigento | Superintendence of Siracusa | Regional CH Department | |
| XVI c. Palermo (B) | XVI c. Enna (E) | XVII c. Trapani (B) | XVII c. Trapani (B) | XVIII c. Agrigento (B) | XIX c. Siracusa (B) | XIX c. Palermo (B) | |
| OFFICE | | MIX FUNCTION | | ARCHAEOLOGICAL SITE | | | |
| OTHER ZONE | XX cent. BUILDING | MULTIFUNCTION BUILDING | MONUMENTAL COMPLEX | ARCHEOLOGICAL PARK | | ROMAN SITE | |
|  | | | | | | | |
| Superintendence of Caltanissetta | Superintendence of Ragusa | Casa Vaccarini Museum | Palazzo Ajutamicristo | Valle dei Templi | Selinunte and Cave di Cuse | Villa Romana del Casale | |
| XVI c.Caltanissetta.(D) | 20s -Ragusa (C) | XVI c. Catania (B) | XI c. Palermo (B) | Agrigento (B) | Selinunte (C) | P. Armerina(D) | |

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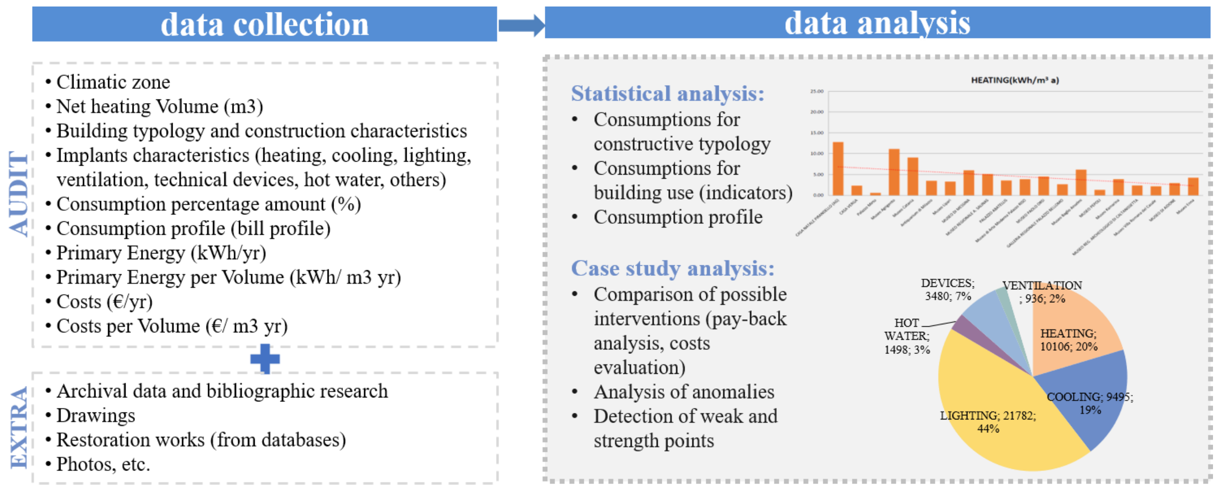


**Figure 1.** Data analysis method.

## 3. Results of the case studies analysis

### *3.1. Energy diagnosis*

By merging all diagnosis drawn up by the Sicily Region in a single computational system, it was possible to recognize symmetries and anomalies among cases and different functions on a large scale. The reports were carried out based on the EN 16247-2: 2014 standard for energy audit [13]. Starting from general building data (orientation, envelope characteristics, net and gross surface and volume, S/V ratio, presence of shadings surfaces, etc.), real consumptions (from energy bills) have been reported to each net heating volume, to be able to compare different buildings in relation to plant types and conditions of use. These data are also highlighted for time slots (f1- morning work, f2- afternoon work, f3- nightly and festive weekdays). The building performance is also given using a quasi-static simulation software, inserting all known building and implants data as input. The portion of consumption attributable to each energetic sector (heating, cooling, lighting, ventilation, water heating, technical devices, etc.) is then summarized in primary energy (kWh/yr), %, costs, TEP/yr and ton$CO_2$.

It is also to underline that these buildings are in different climatic zones, from zone B (Agrigento, Catania, Messina, Palermo, Trapani, Siracusa) to E (Enna), that means from a warm to a cold climate.

Comparing all consumptions diagrams, a first interesting data is obtained: the average consumption profile is higher in the f1 time slot (48%), followed by f3 (32%) and f2 (20%). This means an anomalous consumption in evenings and festive weekdays, whilst most of the buildings are closed. In Pirandello's House, for example, 40% of the total consumption are in f3, in the Ancient Theatre Museum they reach up to 44%. It may be attributed to some lack in the building use and management, as no attention in shutting down implant systems during the days-off, with a consequent huge waste.

In the comparison between real consumption (bills) and calculated data, there is a delta that even reaches a 20% difference in total consumption. On the one hand, this is certainly linked to the error rate given by the insertion of unknown data. In fact, it is highlighted how diagnosis made on ancient buildings (whose envelope and microclimatic parameters are not constant or standard) present a greater difference compared to those for modern ones. Moreover, the quasi-static calculation system does not consider the massive masonry thermal gradient (especially that of summer period). On the other hand, it should not be easily attributable to just a calculations randomness. In order to understand the causes of each building' waste, a detailed analysis on the field is required.

*3.1.1. Heating system.* The energy related to heating corresponds to an average value of 27% of whole consumption (49823 kWh/yr). For buildings in climatic zone D and E, it's equal to 80-90% (about 4.50 kWh/m$^3$yr) due to a greater need. In general, most cases have non-centralized or more ancient generation systems, with low yields. None of the buildings use renewable resources; just 11 have introduced a performing condensation heating technology. The most common terminal units are fan coils and radiators, with only one case of radiant floor panels (Palazzo Abatellis). The energy vector is the electric one, with in few cases a methane use (just 6 on the total), influencing the general costs.

It seems that the highest average consumption value occurs in museums (58213 kWh/yr), with a more staggered subdivision during the day. However, this data compared to $m^3$ is lower than that one reported to libraries (4.78 against 7.94 kWh/$m^3$yr), albeit with due distinctions.

Some anomalies can be highlighted: in Pirandello's House (climate zone B) the 12 kWh/$m^3$yr consumption value results very high for a building of just 976 $m^3$ of volume. It's clearer comparing this data with the 5.1 kWh/$m^3$yr of the Salinas Museum, a building 29 times larger (29063 $m^3$).

In the offices, average consumption for heating (32811 kWh/yr) is not very representative given the great variability of the cases: the largest is the Superintendence of Syracuse (11.21 kWh/$m^3$yr), followed by the Superintendence of Agrigento (7.18 kWh/$m^3$yr); on the contrary, very low values are in the Trapani area (Palazzo Milo 1.41 kWh/$m^3$yr and Palazzo Fontana with 0.81kWh/$m^3$yr). The anomaly of the Trapani's cases data could be explained by the observation of their conditions: in Palazzo Fontana, the small number of workers respect to the building volume implies little consumptions per cubic meter; in Palazzo Milo, the closure of a building section (for structural problems) affects the total consumption: not fully using the building, even the plant is turned off.

**Table 2.** Heating system: synthesis of results.

| | MUSEUMS & HOUSE- MUSEUMS | OFFICES & MIX | LIBRARIES |
|---|---|---|---|
| Average consumption | 58213 kWh/yr (4.58 kWh/$m^3$yr) | 32811 kWh/yr (3.82 kWh/$m^3$yr) (but high variability of cases) | 54733 kWh/yr (7.94 kWh/$m^3$yr) |
| Average % of consumptions | 39% (80-90% in zone D /E) | 31% (80-90% in zone D /E) | 39% |
| Annual average costs | 10044 €/yr (0.74 €/$m^3$yr) | 5676 €/yr (0.62 €/$m^3$yr) | 9468 €/yr (1.37 €/$m^3$yr) |
| HVAC system for heating | •all-air system (just in 3 cases)<br>•air-water system<br>•all-water system with methane or electric heater<br>•heat pump for single room (no centralized system) | •air-water system<br>•heat pump for single room (no centralized system) | •air-water system<br>•heat pump for single room (no centralized system) |
| Terminal units | •fan coils<br>•radiators<br>•split units | •fan coils<br>•split units | •fan coils<br>•split units |

*3.1.2. Cooling system.* The cooling part corresponds to an average of 20% of the total consumptions (40780 kWh/yr approximately), resulting 7 percentage point lower than the average heating load. This may seem to be an anomalous datum, since in Mediterranean climate during the summer period the climatic excursion is stronger as the need for a climatic improvement. But it could be justified by the uneven distribution of cooling system: in most cases in fact (especially in offices) we find splits, temporarily and occasionally inserted with single units placed on the external façade. In museums, on the other hand, in most of the cases we find fan-coils with double functioning (heating and cooling together). In the hypothesis of introducing a cooling system to control T° and RH in the summer in the lacking case studies, consumption would increase considerably, maybe overcoming heating costs.

Anyway, cooling data show a much higher average value in museums (51534 kWh/yr) than other uses: offices and libraries present similar data with a difference of a few hundred kWh per year (38691 the first and 38662 the latter). The anomalous data appears to be, as for heating, that of Pirandello's House with a value of 11.64 kWh/$m^3$yr.

From this analysis, it has been noticed how modern buildings, having large windows and less massive structures, consume more than the equivalent ancient ones, which have a greater thermal inertia: the heating-cooling average cost for ancient buildings is around 1.90 €/$m^3$yr, whilst for modern ones is 3.50 €/$m^3$yr, albeit with exceptions. For example, in the case of the Museum of Messina, designed in the 60's by Scarpa and Calandra architects with large floor-to-ceiling windows, consumption amounts to around 6 kWh/$m^3$yr (for a total of 41030 €/yr) both for heating and cooling (being almost equivalent). The historic Palazzo Abatellis, XVI century building in tuff stone with small openings on the inner courtyard, comparable to the first for size, is more performing with its

3.26 (cooling) and 3.57 (heating) kWh/m$^3$yr, although it has an even lower performance HVAC system.

**Table 3.** Cooling system: synthesis of results.

| | MUSEUMS & HOUSE- MUSEUMS | OFFICES & MIX | LIBRARIES |
|---|---|---|---|
| Average consumption | 51534 kWh/yr (3.72 kWh/m$^3$yr) | 38691 kWh/yr (3.66 kWh/m$^3$yr) | 38662 kWh/yr (2.86 kWh/m$^3$yr) |
| Average % of consumptions | 26% | 20% | 27% |
| Annual average costs | 9276 €/yr (0.66 €/m$^3$yr) | 6693 €/yr (0.63 €/m$^3$yr) | 6688 €/yr (0.49 €/m$^3$yr) |
| HVAC system for cooling | •all-air system (just in 3 cases)<br>•air-water system<br>•heat pump for single room (no centralized system) | •air-water system<br>•heat pump for single room (no centralized system) | •air-water system<br>•heat pump for single room (no centralized system) |
| Terminal units | •fan coils<br>•split units | •fan coils<br>•split units | •fan coils<br>•split units |

*3.1.3. Lighting system.* By analysing each type of energy system, it was difficult to compare lighting data. The average consumption corresponds to 25% of the total but building typology as well as building function has an influence on this aspect, together with the lighting fixtures models. In museums, for example, rooms are illuminated differently according to design choices, with an average consumption value of 4.93 kWh/m$^3$yr (33% of the total). In many of these cases lamps are HQL or fluorescent tubes within 58W, while for the outside lighting we find halogen lamps even from 1000W. In some rooms there are also directional spotlights and (only in rare cases) LED strips.

In libraries and offices, we have mostly fluorescent ceiling lights (usually 2x36W). In this case, lighting consumptions have an average cost of 0.5€/m$^3$yr (22% of the total), mostly in the f1 time slot.

In archaeological areas lighting corresponds to the 50% of total expenditure (which is understandable not having large consumption in the guardians' buildings). Many halogen lamps are necessary to highlight historic remains from afar. In cloisters, lighting is a big slice of total energy costs too: at the Magione's Cloister as well as at the Cloister of S. Giovanni degli Eremiti is equal to 60%.

It's important to underline that buildings of different ages and constructive techniques, ancient and modern (and therefore more glazed) ones, do not show substantial differences. Although some buildings may boast more natural light, this is not taken into consideration by the building lighting system since there isn't any lamp dimming control, causing waste and possible visual discomfort.

**Table 4.** Lighting system: synthesis of results.

| | MUSEUMS & HOUSE- MUSEUMS | OFFICES & MIX | LIBRARIES | ARCHAEOLOGICAL AREAS & CLOISTERS |
|---|---|---|---|---|
| Average consumption | 45076 kWh/yr (4.93 kWh/m$^3$yr) | 30861 kWh/yr (4 kWh/m$^3$yr) | 40697 kWh/yr (2.55 kWh/m$^3$yr) | 40326 kWh/yr |
| Average % of consumption | 33% | 22% | 22% | 53% |
| Annual average costs | 7254 €/yr (0.82 €/m$^3$yr) | 5339 €/yr (0.55 €/m$^3$yr) | 7040 €/yr (0.44 €/m$^3$yr) | 6976 €/yr |
| Lighting principal functions | •to highlight artworks<br>•in windows<br>•distribution areas | •workers' desks<br>•conference rooms<br>•distribution areas | •readers' desks<br>•workers' desks<br>•distribution areas | •to highlight excavations and archaeological areas<br>•pathways |
| Prevalent lamp typologies | •HQL lamps<br>•fluorescent lights<br>•halogen lamp (exterior)<br>•spotlights<br>•ledstrips (windows) | •fluorescent ceiling lights (2X36W)<br>•ceiling spotlights<br>•led lamps (single lamp substitution) | •fluorescent ceiling lights (2X36W)<br>•led lamps (single lamp substitution) | •halogen lamp (exterior) |

*3.1.4. Ventilation system and Hot Water system*. It does not seem to particularly impact on the consumptions: in many cases we do not find specific plants, except for recent interventions and especially in offices. It is therefore not possible to have a reliable comparison between cases.

Likewise, the rate corresponding to domestic hot water does not affect the general budget significantly, except for a maximum of 5% in offices (Superintendence of Ragusa 2.32 $kWh/m^3yr$, Superintendence of Caltanissetta 2.40 $kWh/m^3yr$) where therefore we have a constant flux of people.

*3.2. On-site survey*

Onsite surveys have made possible to describe building construction techniques, hygrothermal behaviour and materials conservation conditions (water presence as moulds, discontinuities, windows damages, etc,) with accuracy. Inspections took place between June and August 2018, in order to verify major problems in summertime. Possible relations among deteriorations and building materials or artworks unsuitable thermal conditions have been highlighted. Furthermore, users' comfort perception and artworks conditions have been verified with the aid of a thermographic camera, a luxmeter and a T° and RH measuring instruments for evaluating the feasibility of preliminary retrofitting scenarios.

Construction types vary between ancient and XX century buildings. The first have wall structures in limestone (tuff) or lavastone (in the area of Catania) with a secondary wooden structure, sometimes painted (Palazzo Ajutamicristo) or with fake vaults (Palazzo Mirto); modern buildings instead (of the 30's, but many others of the 60's by Minissi architect) are distinguished for their material lightness, designed to create light games inside, with loggias, glass roofs, arcades, solar chimneys and large windows; important examples of architecture with obvious shortcomings in terms of energy waste.

However, buildings are complex systems and in some cases there's an overlap between different construction phases. For example, the archaeological Salinas Museum, XVI century building, has been redesigned in the XIX century previously and again during the last year, with an enlargement of the exhibition area around the three cloisters with a new glass roof. Or the case of the Griffo Museum of Agrigento, where the previous museum exhibition designed by Minissi has been upset in recent years by sporadic interventions, far from an understanding of the functional system. The closure of the existing natural ventilation openings and the plugging of light chimneys above showcases, have altered the idea of original bioclimatic design. Similarly, in the Pepoli Museum, natural ventilation guaranteed by punctual nozzles was closed during the roof insulation work, causing temperature peaks in the summer (detected during the survey campaigns) up to 28°C (with external T equal to 25°C).

For almost all case studies a common problem is the lack of maintenance, both of building and plants. One of the main issues for older buildings, as with porous materials, is the presence of water and the variation of the relationship between T° and Humidity [14]. In the Antiquarium of Milazzo, we find huge problems due to a rainwater percolation from the rooftop, causing widespread efflorescence and microbiological formations on the north-west walls. Observing the roof, it was seen how the downspouts, embedded inside the walls, are obstructed by caper weeds, also present at the building basement. A simple periodic check and the predisposition of a leaf filter grill would have been enough to remedy the problem. Pirandello's House presents important problems of water capillary ascent, but during the visit it was possible to recognize the cause in a drainage water pipe just in correspondence of the masonry. The simple verification and replacement of the pipe could easily solve this long-standing question. In Palazzo Abatellis, on the other hand, there was a mould problem due to condensation damp in the basement floor corresponding to the staff changing room. During the survey it was observed how some cabinets were closing an air channel causing this problem, easily to be solved with the reopening.

For many observed wooden windows frames (Regional Library of Palermo, Superintendence of Syracuse) simple low-cost repair actions would avoid air infiltration, discomfort and energy losses.

Sometimes solving simple problems can positively affect the overall energy balance of buildings [15], but the key is to actively involve users [8].

This point is accompanied by the question of plants maintenance. The HVAC system are often not in function, due to a lack of regular controls: in the Museum of Messina, for example, the latest generation of machines has high running costs and maintenance is not always sustainable; hence, in case of failure, part of the building can remain for long periods without conditioning, with strong temperature variations between the rooms.

The most serious problem therefore appears to be the total lack of control of the comfort requirements, both for users and objects. For example, in the halls of museums, as well as in convents, there are no sensors for any microclimate monitoring, fundamental instead for a well-done preservation of works not kept under controlled protection barriers. Collections range from 'hard' materials such as sculptures to 'soft' such as fabrics, curtains, furniture and so forth. All of these are subject to deterioration through time because of pollution and physical changes through temperature and humidity fluctuations, albeit it at different rates and in different ways. "The safest way of avoiding such deterioration is to provide environmentally controlled exhibition and storage spaces. However, this is not currently the case at many buildings due partly to the high capital and running costs involved, and partly due to concerns about effects on the building fabric" [16].

For example, the room dedicated to the restoration of masterpieces in Palazzo Abatellis, has an inadequate conditioning system: the ceiling air-air system, with a very low and high-speed air supply temperature, not the most suitable for works conservation. In the exhibition rooms, many artworks are placed in protective cases, even these verified by sensors only occasionally. There are temperatures in June equal to 21°C on the ground floor (with an external temperature of 26°C), with temperature changes of +4°C in the lateral rooms and +7°C on the upper floor. This is also the case of Baglio Anselmi of Trapani, where the rooms have parameters that are clearly unbalanced among themselves, despite the recent restorations.

The light is another topic to be discussed: lighting system often is not calibrated to the needs. For example, it's not always able to highlight correctly outside crosswalks for visitors (Ancient Theatre Museum) or to illuminate artworks in museums avoiding glare effects (Pepoli Museum).

Furthermore, the illuminance to guarantee a visual comfort is not defined in the energy diagnosis and it was checked during the on-field survey with the help of a luxmeter. It was found, for example, that in most of the visited offices there was a lack of homogeneity of lux on tables (range 40-550 lux) decidedly unfavourable for workers. Also in museums, it was found a lighting problem due to reflex on the glass showcases (Salinas Museum). In libraries (Library of Catania), artificial light with fluorescent tubes cannot guarantee a level that is suitable to the needs of the readers (150 lux against 500 lux provided for by the standard for lighting level, UNI EN 12464-1). How much natural light affects the environment and how much it is possible to dim the lamps is not a datum inserted in the diagnosis, that should also be detected for a correct positioning of lamps from an architectural and design point of view.

This also includes the topic of shadings: how much the tents and the sunscreens are used is not known. But as far as we could see, shutters were not so much used (due to their poor conditions or to a lack of people habits) and, if present, other shading systems (e.g tents) are the result of self-made adaptations. Certainly, an adequate behaviour along with the use of performance materials such as films, curtains with nanotechnological materials, could benefit from current conditions.

In the case of the archaeological sites, problems are mostly linked to a wrong positioning of the lamps or to a bad choice of lighting fixtures for lighting the remains. Hence, high consumptions with low yield. But even in this case, the lack of maintenance disadvantages a more sustainable and efficient use of lamps. In the case of Baglio Anselmi, for example, recent restorations have provided only the implementation of the pathway along the routes in the archaeological area; however, the presence of weeds, the lack of recognizable flooring as well as the negligence in which the entire roofing and lighting system over the Roman mosaics occurs, makes the site not fully accessible.

**Figure 2.** Collection of examples: buildings and artworks with poor maintenance conditions; implants insertion without an explicit logic. (Photos by Buda 2018)

*3.3. Stakeholders interviews*

It was essential to interview different users (including building managers and local heritage officers) to get an overview of management and needs, noting problems and singularities in each building during the year. From what has emerged, the management of the building-plant system often takes place without any protocol or regulation. From interviews to the museums' managers, for example, it emerged that it misses an appointee turning off plants at the building closure in almost all cases (hence plants remain in function also during the night or in the days off, with a high waste of energy).

This is also translated into an arbitrariness both in the definition of the plant set-points (if not centralized), but, above all, in the variability of consumption linked to the single human behaviour. One example is the windows opening while the system is on, because people do not expect that the temperature is going to be stable, or the non-switching off lights at the closing time or when the sunlight filters inside during the morning, the lack of caution in closing shadings systems when necessary to sunscreen, etc. These shortcomings arise, on one hand, from a problem of understanding the system, on the other hand from a discomfort. The latter is due to factors not only socio-psycho-cultural, but also from an inadequate or poor design of the indoor microclimate.

In fact, in many cases it is evident the lack of an integrated design of plants, with the consequent implementation of "spot" or temporary solutions with little respect for the historicity of the place (see for example the traces for the passage of installations on the façade of the Regional Library in Palermo). An example is the presence of splits on the facades (as in the case of the Verga's House). In some cases, this is accompanied by an incompatibility between the building, as originally planned, respect to the function that has been conferred over time. Very compact buildings with only few windows are not much suited to the office function, if not well oriented and designed. In these cases, attics are often used to accommodate staff, with excessive heat problems during summer (29°C with splits on at the Superintendence of Trapani) and lack of adequate direct light.

*3.4. Retrofit interventions: feasibility and discussion*

In order to prove that this experience can contribute to the improvement of regional policies for a sustainable built environment in Mediterranean context, numerous strategies, from an energy and conservation standpoint, have been considered. In the balancing test between diagnosis and buildings conditions many issues arose: the main retrofit principle was to define measures for reaching both a better building preservation and management 'doing as much as possible' according to the building constraints. This requires the adoption of measures (also non-standard ones) linked to each case and to the already present resources. Interventions were evaluated according to a variety of criteria, that can be grouped in four principle categories: heritage, economy, environment and society (Table 5).

**Table 5.** Criteria and targets used to assess the impact of retrofit interventions.

| | CRITERIA | TARGETS |
|---|---|---|
| HERITAGE | **Heritage significance of the building and its settings:** Evaluation of the context and respect for historical, constructive, conservative and dimensional constraints | Material impact on heritage value<br>Visual impact on heritage elements<br>Possibility to recover heritage components<br>Heritage maintenance |
| | **Technical compatibility:** Non-invasiveness and integration of the system and compatibility with respect to specific conservative needs | Material compatibility<br>Reversibility<br>Evidence of the intervention |
| ECONOMY | **Economic viability:** the cost will be evaluated from the initial phase of installation, up to the relative part, consumption and expected duration | Capital costs<br>Operational energy costs<br>Payback Time<br>Maintenance and replacement costs |
| ENVIRONMENT | **Energy efficiency:** less consumption and higher efficiency, plus sustainable interventions | Annual primary energy<br>Annual $CO_2$ emissions<br>Consumption profile<br>Embodied energy |
| | **Hygrothermal behavior:** control on the intervention performance and durability | Thermal bridges reduction<br>Internal surface temperature control |
| | **Indoor environmental quality:** ensure the environment indoor quality (variable targets, depending on the building use) | Air filtration rate control<br>Removal of decay problems<br>Thermal / Lighting/ Acoustic comfort |
| | **Objects preservation: preserve collection** avoiding agents of deterioration | Microclimate control (T° and RH)<br>Pollutants |
| | **Impact on outdoor environment:** low impact on external space | Respect for the historical environment |
| SOCIETY | **Aspects of use:** Ease of control and maintenance | People involvement<br>Management and maintenance protocol |

The majority of measures is planned in buildings situated in climatic zone B; therefore, a particular attention will be given to reducing consumptions and to enhancing the internal comfort during the summer period. The latter in fact represents the heavier period either for the high temperature reached in Sicily, either for the internal gains due to the touristic presence during the season.

Each building’s typology set restrictions on the exteriors, due to its historical and artistic interest. This leads to the result that it is not possible to intervene on the façade with standard solutions. It could be evaluated the hypothesis of using new nanotechnological products or materials; but to be sure to avoid inconveniences, it could be done just after experimentations which could validate their reliability.

Also the windows substitution is claiming as a compromise between the needs of increasing the asset performances and the necessity of maintaining the architectural integrity of the construction: the replacement will be done only where the architectonic constraints or the state of decay allows it (e.g in the Superintendence of Enna); in the other cases, a restoration will be carried on, perhaps adding a reflective film, only after the compilation of an abacus for every case.

The stained glass designed by Carlo Scarpa for Palazzo Abatellis are an emblematic case: they are under performing from the energetic point of view. Nonetheless, they are part of the history and material and constructive culture and their substitution would result in very little advantages: with a costs reduction of 4% and a payback of 15 years, but with serious cultural loss and environmental liabilities (the windows disposal and the production of new ones have in fact a significant impact).

Intervention strategies in correlation with the different intended use have been identified for the energy efficiency of the lighting equipment.

For the offices and libraries, the idea is maintaining the existing lights sources, where possible and only if they still fulfill the comfort conditions for people and with acceptable levels of decency.

In the archeological sites, lighting will be redesigned considering the fruition, and with attention to the quality of light (color, blur effect, etc.) and of the light sources. The design will be developed to valorize the monuments, considering noninvasive lights, hidden from view if possible, avoiding theatrical effects or light pollution.

In the museums the lighting feature will be completely rethought. Many among them have lighting systems realized in previous interventions, but in many cases outdated and inadequate to the current preservation needs and fruition of artworks. Therefore, in museums or for museum installations, the efficiency project of lighting components will be designed with attention to the light quality, that means evaluating the aesthetic of lighting fixtures to replace, underlining the value of oeuvres, making choices that can simultaneously guarantee a high-quality lighting in museum exhibitions, while ensuring the reduction of consumptions.

As regards HVAC system, except for very few sites, plants are in bad or lacking conditions. Therefore, the first measure must be oriented to guarantee a full functionality of the distribution facilities -*sic et simpliciter*- regardless of efficiency enhancements, if any. In many cases interventions can be limited to a careful ordinary maintenance.

For an overall good setting of the air conditioning system, the main issue is to maintain the scheme of the existing distribution system. It allows the existing plant to reach the maximum level of efficiency and its good functioning could be guarantee with just systematic interventions on the distribution network and on machines. This could be accompanied by the study of existing passive air conditioning systems, rediscovering channels and grids that can be maybe reopened or used differently, positioning other tubes.

However, wherever it is economically and technically feasible, it is planned to replace heating/cooling systems with hot and cold production systems with higher energy efficiency and less environmental impact. The prerogative will be to limit any intervention on the building to not compromise the historic building heritage.

During the design process, the ITQ and people satisfaction should be the priority, to be evaluated starting from an adaptive approach to verify comfort levels case by case.

According to the standards for the microclimate control for the conservation of cultural heritage (EN15757: 2010) it is recommended to maintain the historical climate, to be measured before and after any intervention [17]. This procedure makes it possible to verify any possible changes in RH in the case of a new installation of air conditioning system. Then, to facilitate the management of the building-plant system, it could be possible having specific cognitive tools. One of these, for example, is the monitoring protocol developed by ISCR's scientific experts for a systematic survey of environmental data, aimed at achieving those conditions deemed optimal for conservation. This sheet has already been tested and validated in several museums to verify its usefulness and effectiveness as a tool for analysis and control.

Furthermore, the real estate assets of the Department of Cultural Heritage of the Sicily Region could be equipped with an information system (Energy Building Management Information System) to acquire and process data on buildings conditions and procedures, in order to outline an energy improvement plan. Starting from the mapping of data, the tool will define the execution, planning and redevelopment of management actions to achieve expected performance goals, as well as planning maintenance, requalification, adaptation and energetic improvement.

Finally, the topic of renewable energy sources insertion, such as PV, is particularly controversial. As a support it could be useful to follow the indications provided by the Guidelines of the Italian cultural heritage Ministry (MIBAC) [5] in order to minimize the visual impact. They are the following:

- if possible, place panels on the parking areas adjacent to the building;
- study the arrangement of panels as a continuous strip, above the gutter line, along the entire length of the roof. If not possible, cover the entire pitch which has the best exposure: in this way the panel surface is less invasive, compared to the visual fragmentation of the pitch;
- choose compatible colour solutions, in the case of insertions on the roof (grey slate, brick red of the tiles etc.), on the walls, on the fences.

**Figure 3.** Few examples of windows and shadings to be preserved.

## 4. Conclusions

The uniqueness of this experience (still ongoing) is the numerousness of the cases and the data quantity. It also proves what we have written in the introduction about the importance and utility of different knowledge working together for the preservation of built heritage in fact it was fundamental to add qualitative data and analytical survey of each building condition to set an effective and efficacy planning. Too often energy audits do not consider the state of condition of the building, as its context, its uses, its users, but it is no less true the contrary. Very often after restoration works the ancient building behavior results to be deteriorated, because its constructive properties, potentialities and microclimate aspects had not been properly considered.

The (not always successful) framework which has emerged from the study is in the reality very common: lack of maintenance, weaknesses in the management, inadequate involvement of who, in one form or in another, lives these places.

Therefore, the idea is to work together using (after adequate phases of experimentations that we hope could be financed) either innovative materials and techniques, either on the contrary, passive and ancient systems which regulated the internal climate when no other methods were available.

The main point that must be underlined, and that remains at the center of our experience, is to make clear that in this domain what really matters are not just money or energy savings, intended in a mono-dimensional direction. In fact, working carefully on the microclimate changings allows a saving, but - above all- a better conservation of the heritage, preserving its values.

In this moment, it seems to prevail numerous misunderstandings about the notion of sustainability: elements of ancient constructions are frequently substituted by virtue of an ‘environmental attention’ that it is still to be demonstrated, with no regard for the entire life cycle of the parts.

On the contrary, there must be a reflection on the choice of retrofit measures, defining the best way to obtain optimal conditions of usability and protection without compromising the cultural and historical values of the buildings. For this purpose, it is fundamental to consider energy efficiency and actions aimed at sustainability as innovative forms of protection of the heritage itself, fully integrated in the restoration project [18].

The objective of the study is twofold: to analyze the performance conditions of a historic public buildings sample in Mediterranean area, through both calculated and measured data, and to verify the impact of possible enhancing actions. The latter will be reached through an accurate analysis in situ of their contexts and of their problems and possibilities.

The acquired knowledge provides a good information basis on which it is possible to elaborate local strategies and decision-making instruments. It will substantiate the design and the verification of interventions compatibility. Dealing with built heritage may lead in fact to a paradox as the interventions aimed at achieving excellent performance values and cost savings could jeopardize the uniqueness of the existing construction, simplifying a complex problem into the exclusive reasoning of saving energy and costs [19].

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