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Energy efficiency and renewable solar energy integration in heritage historic buildings

Cristina S. Polo López[a,*], Francesco Frontini[a]

[a]SUPSI, University of Applied Sciences and Arts of Southern Switzerland, Trevano CP 105, Canobbio CH-6952, Switzerland

Abstract

When facing a retrofitting project which tries to improve the energy performance of a cultural heritage building it is necessary to weigh carefully different aspects such as: energy efficiency, modernization and comfort. These energy improvements are desirable, but are not always possible without compromises. The situation may become slightly problematic when solar energy systems should be installed in historic buildings. The first step to overcoming barriers successfully, is to better understand the processes for both, historic preservation and solar PV project implementation, and to foster working with professionals in each sector to receive appropriate support and guidance. Establishing an assessment criterion for each step was the top priority of the research project presented here to assist in achieving a successful result.

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Keywords: Historical buildings; Cultural heritage; Energy performance; Solar energy integration; Building renovation; Renewable Energy;

1. Introduction and general framework

1.1. Energy efficiency in historic buildings

Historically significant buildings are listed on local, national or international register providing certain degree of protection. Any physical alteration, including repairs, additions, refurbishment, energetic renovation, etc. to these

* Corresponding author. Tel.: +41-(0)58-666-6314; fax: +41-(0)58-666-6349.
E-mail address: cristina.polo@supsi.ch

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important properties requires review and approval by the corresponding official body. When designing an intervention aimed at improving the energy performance of a historical building, the project development process must consider a number of factors: the historical features to be protected, the final use of the building as a whole, the energy and comfort requirement for people and artworks. High performance window frames, well-insulated opaque surfaces and claddings, efficient thermal installations and passive techniques for heating and cooling are all interventions aimed at reducing the consumption of the building, and which must be assessed in the early stages of the design. For protected historic buildings it is not possible to operate freely especially if one considers that the attitude related to the necessity of intervening "energetically" may thwart the desire for conservation and in some cases be almost irreconcilable. Solutions such as high performance window frames, well-insulated opaque surfaces and claddings, efficient thermal installations and passive techniques for heating and cooling to reduce the consumption of the building must be assessed in the early stages of the design.

The construction standards to which these buildings were built differ from those in place today, and often do not meet current energy and comfort needs. Only rarely it is possible to vary the envelope's elements of protected buildings, since the aesthetic appearance would be affected, but these elements perform a fundamental role in ensuring a good level of thermal insulation. In fact, the objective of a historical building energy adaptation project is to improve the levels of comfort and to reduce the energy consumption required for heating, lighting and other purposes. Historical buildings often represent interesting construction models associated with the local area, the financial use of materials and local building methods. Historical buildings often require specific micro-climatic conditions. It is sometimes necessary to find a balance to satisfy the requirements of the building, the occupants and the exhibited objects, also considering that the "well-being" of people does not usually correspond with the "well-being" of objects and collections [1].

In order to cope with the challenges set by today's society, and to meet local and international legal/regulatory requirements towards energy efficiency and zero energy consumption [2], there must be more in-depth discussion between all the technical field experts and all the involved parties. Just a few of European [3, 4] and national [5, 6] research projects have already proposed innovative approaches to raise energy efficiency through urban development and the refurbishment of the building stock. It is also important to consider that future action in our cities will involve the redevelopment of existing buildings, with the aim of reducing the extent of land coverage. For now, and for the near future in the construction field, it will be even more necessary to execute work on the existing heritage, in order to use the ground in a sustainable manner by means of more effective use of zones that have already been built. In order to slow down the process of messy city expansion, the issue of densification is now under discussion. Furthermore the need for high-quality densification of urban settlements is also gaining ground in public opinion [7].

It is therefore necessary, to develop a working method that is as objective as possible and that will reduce the possibility of contradictions based on personal and arbitrary appreciations. Moreover, to identify the best ways for energy saving while at the same time, respect the historical, and cultural value and its environment, a correct approach that evaluates all parameters in an integrated assessment studying the building components as well as the typological and functional parameters in order is needed. By "cultural approach", we mean close collaboration between those appointed to execute the work, under the careful direction of the institutions responsible for protecting the building.

1.2. Solar energy resources

As highlighted before, the new regulatory framework together with the increasing densification of cities, lead to consider the importance on using solar technology also for historical buildings [8]. This option has not been properly utilized yet because of psycho-social barriers and lack of information [9]. Furthermore, there are worthy examples, based on meticulous research aimed at appropriate integration, and that demonstrate the enormous potential of integrating these elements into historical buildings.

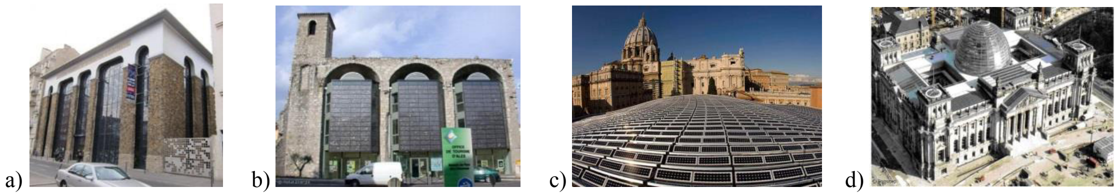

Fig. 1. Some examples of building integrated Photovoltaic system on historical buildings: (a) Hotel Industrial, Paris (France), 2008 . Source: Tina Roach AIA; (b) Tourist office, city of Alès (France). Source: CLER, Solerte; (c) Sala "Nervi", Vatican City (Italy) - 2007 European Solar Prize. Source: Eurosolar Italy; (d) Reichstags building, 1999 Eurosolar 'Solar Prize in the field of Renewable Energies'. Foster+Partners Architects.

2. EnBAU research project approach

ENBAU "Energie und Baudenkmal" research project have been promoted by Stiftung zur Förderung der Denkmalpflege (Foundation for the Promotion of the Conservation of Historical Monuments) [10]. The aim of the project is to identify appropriate solutions for reducing energy requirements as much as possible, also by incorporating renewable and solar energy, trying to achieve an optimal result by exploiting the very features of the building and of the surrounding environment. The final objective is that, already during the preliminary phase, it will be possible to choose a renovation project with a high level of sustainability to ensure and improve the level of comfort guaranteeing a high-quality and cost-competitive construction process. Project activities have been organized as indicates in Fig. 2.

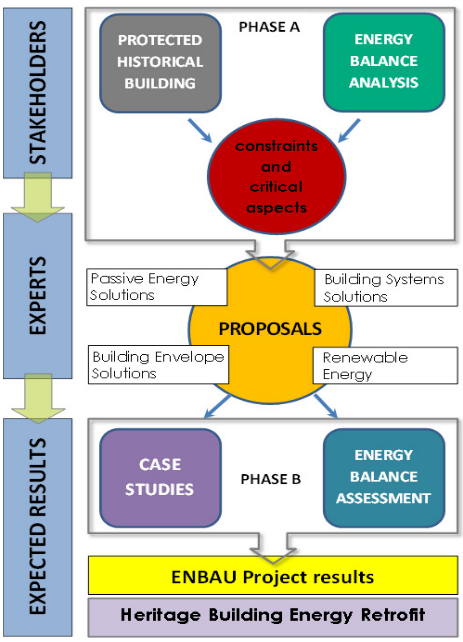

Fig. 2. Identification of the adopted methodology.

Protection demands and energy savings requirements are two factors that must both be satisfied since they are important for the sustainable use of resources and for quality of life. So it is important to find customized solutions that can integrate these two requirements in a harmonious approach, limiting the strain that undoubtedly arises if the work is planned without having been thought out in an integrated manner. Each design solution has specific objectives and requirements which must be considered and assessed in a logical manner:

- Objectives to reach;
- Client's needs and stakeholder requirements;
- Features of the historical building: external envelope, internal structure, surrounding environment, current energy assessment, final use;
- Analysis of the critical aspects and regulations;
- Feasibility analysis of the solutions proposed: impact on the building, effect on the environment, reversibility, costs, etcetera.

To facilitate the communication and the understanding between the various actors participating in the renovation and energy optimization of a historic building, a suitable methodology that provides a valid decision-making tool, as outcome of discussion and consensus between all the parties involved in the process of redeveloping a protected architectural structure, was proposed.

This tool must provide an approach to be adopted when selecting inter-disciplinary solutions: the architects, energy consultants, specialist engineers will be carefully supervised by the restorer; they will understand their areas of competence and will therefore be able to set their respective targets. On the other hand, the heritage specialists will be able to assess the efficacy and feasibility of the solutions proposed. In addition to this, public administration bodies can use the results of the project as input for new legislation related to energy improvement solutions for buildings of historical significance. Collaboration between the various stakeholders is essential. The aim is to define a series of interventions, single or cumulative, that will be of unquestionable interest since it will be an example of good practice contributing to global environmental sustainability.

3. Integrated energy retrofitting methodology for historic buildings: Case Studies

Three case studies in Switzerland have been examined, making it possible to define a series of solutions aimed mainly at improving the energy features of the building and the level of comfort inside. The measures proposed vary in accordance with the various levels of priority and feasibility, depending on the need to protect and conserve the building, and are defined, in order to achieve a sustainable compromise between the various requirements.

The three case studies -Anatta House, Monte Verità Ascona, (1904); Manetti House, Bironico, Monte Ceneri, (1600); Hôtel de La Sage, Avolène, Vallese, (1890)- analyzed within the EnBau research project provided the opportunity to apply the proposed methodology to examples with different features and problems, and, in particular, with varying levels of freedom in terms of permissible solutions.

These heritage buildings have been analyzed, making possible to define a series of solutions aimed mainly at improving the energy features of the building and the level of comfort inside. The measures proposed vary in accordance with the various levels of priority and feasibility, depending on the need to protect and conserve the building, and are defined, in order to achieve a sustainable compromise between the various requirements. The most important factor involves the development of a methodological approach that is generic but applicable to the individual case studies, based on easily interpreted charts that can be used to identify the main parameters on which to work, and a set of different solutions that can be selected depending on the execution possibilities.

All the actors involved in the renovation project (architects, renovation experts, owners, technicians, protection officers) must therefore carefully consider the new technological developments, and understand how they can be introduced and integrated into existing buildings.

Protection demands and energy savings requirements are two factors that must both be satisfied since they are important for the sustainable use of resources and for quality of life. So it is important to find customized solutions that can integrate these two requirements harmoniously, limiting the strain that undoubtedly arises if the work is planned without having been thought out in an integrated manner. Although it is not always possible to achieve compliance with current energy standards, it is considered necessary and important -with a view to environmental sustainability and a prudent use of energy resources- to try to improve their energy efficiency as much as possible.

A basic outline of the most important characteristics of the three historic buildings that have been studied are illustrated below in Table 1.

Table 1: Three case studies in Switzerland were selected to apply the methodology of the project. It was decided to analyse only buildings that originally have been residential, constrained by increasingly restrictive levels of conservation protection, and with different intended purposes.

MANETTI HOUSE	LA SAGE HOTEL	ANATTA HOUSE
Preserved and slightly modified during the time	Partially preserved and modifies in present day	Not preserved and with many transformations
		
The building is still a residential house. It was used continuously over the time. The proportion of items with low historical value is great, most of them are in good condition or slightly damaged. In general, there is a good chance of improvement.	The propriety has changed the building during the time but it was continuously used. The proportion of low value historical elements is important; most of them are in good condition. There is a great potential for improvement, especially in the building services (HVAC).	The building nowadays serves as a museum and it was not continued used. The proportion of itmes of high historical value is considerable. Almost all the elements are degraded and damage and contribute to the high energy demand of the building.

4. Energy refurbishment methodology

The proposed methodology allows the potential solutions to be rationalized and the priorities to be ranked, clarifying the potential advantages and disadvantages of the solutions with regard to the features of the intervention proposed. The choice of solution is therefore based on understanding, the higher or lower environmental performance, and other aspects, of the solutions to be executed. Depending on the needs of preservation and conservation of the property, the proposed measures will vary according to different priority and feasibility degrees.

The project activities are organized as follows:

- First step: Current building status diagnosis and first energy balance analysis;
- Second step: Project proposal development - Energy retrofitting solutions and tools to assess measures to enhance and improve the present situation;
- Third step: Assessment of retrofit measures, management, planning and maintenance.

For every step, a simple evaluation model system, summarized in charts, has been proposed considering all the macro areas of interest and subjects, as detailed in Fig. 3.

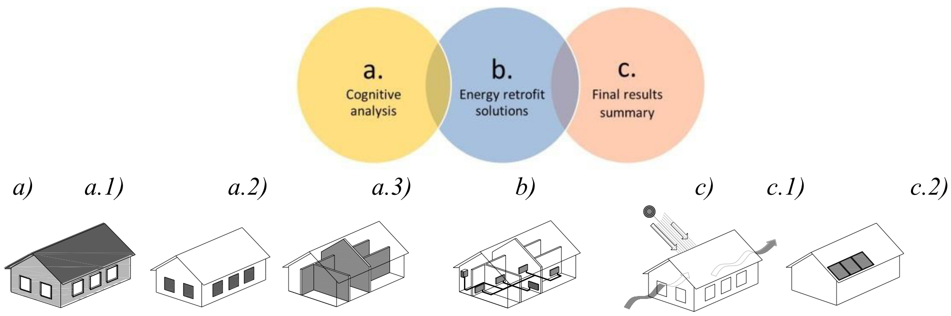

Fig. 3. Symbols are used to identify the areas involved in retrofitting measures: (a) Building envelope: a.1_ façade and roof/ground floor enclosure; a.2_ transparent enclosure; a.3_ Internal enclosures; (b) Equipment systems (electrical / thermal / ACS); (c) Solar Energy solutions: c.1_Solar passive solutions; c.2_Renewable energy sources (photovoltaic / solar thermal / others).

The charts system is divided according to different topics grouped together by development macro-area. The macro area are related to: building cultural value, architectural and constructive features, the local environmental conditions and climatic aspects, comfort improvement and passive conditioning, technological systems status (heating systems, hot water systems, air-conditioning systems, ventilation systems) for thermal conditioning and the integration of solar energy resources. Each topic is assessed by means of an analysis that considers the potential of the solution, the limits and the levels of action. Each sub-system could be subdivided into further sub-categories, therefore expanding the level of information of the general matrix. All aspects can be considered to achieve the goals of improving overall building energy consumption balance. The final energy balance is compared with the initial situation, so the obtained benefits can be checked immediately. This methodology produces, contemporaneously, solutions that can be compared in function with their level of feasibility and impact on the building heritage significant (high, medium or low). The chart system is used for the achievement of quality standards (as example, see Fig. 4, 5 and 6). The main parameters to organized and categorized the charts are:

- ***Color code:*** ***(green, yellow and red dots)*** each energy efficiency renovation's measure is categorized according to an established color code. There is three intervention's level where minimum standard is color-coded green, as a function of impacts on building heritage. Follow-up actions for any improvement are encoded yellow or red.
- ***Symbols:*** are used to identify the involved areas (refer to in Fig. 3).
- ***Indicators:*** to assess energetically refurbishment measures in relation to each historical building.
- ***Scoring system:*** to evaluate these key parameters.

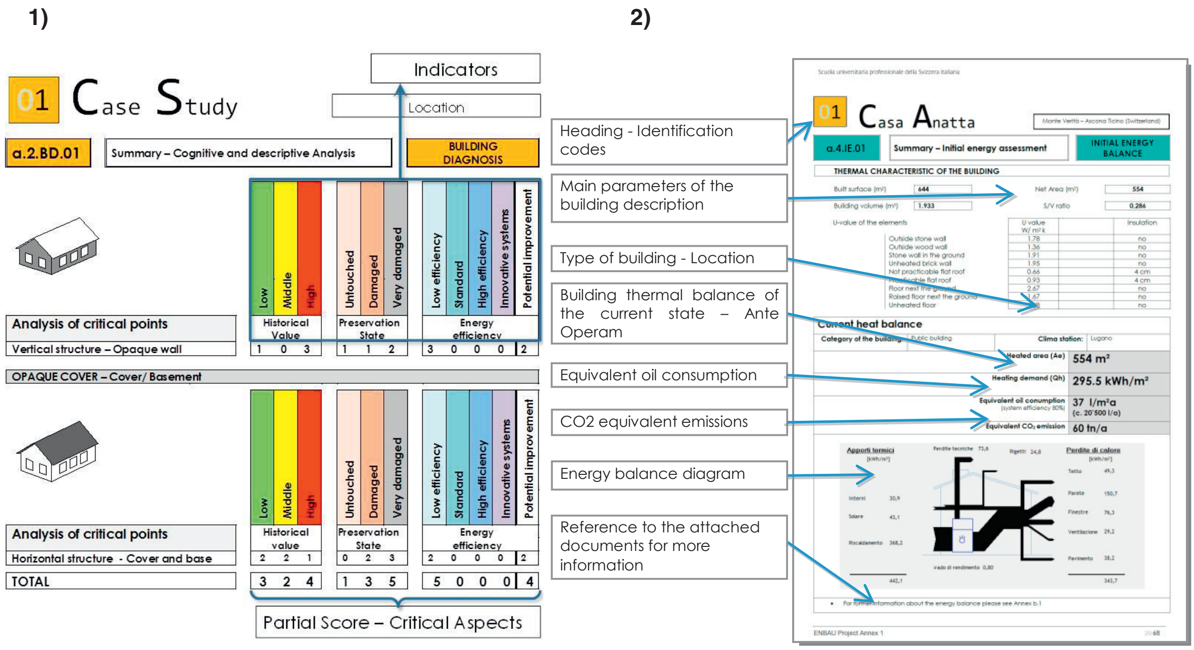

Fig. 4. Example of the charts developed during the preliminary investigation, first step: a. Cognitive Analysis: (1) Part of a "Critical aspects Resume Chart". A code must be established to evaluate the level of criticality and to set the potential alteration limits; the sum of the scores for each indicator quickly gives us a global overview of the most important aspects on which to conduct the proposed work; (2) "Energy balance analysis chart" for setting the current status diagnosis of the case study buildings.

From an energy aspect, this kind of buildings often have high levels of thermal dispersion, while on the other hand they provide a positive inertial mass effect. Nowadays, the use of high-quality insulation materials makes it possible to safeguard internal heat in winter and restrict summer heat from entering, while in the case of historical buildings we must try to understand how to exploit the thermal inertia of the envelope, the aero-illuminating ratios and the possibility of achieving passive control over the microclimatic parameters. Strategies and passive energy solutions contribute significantly to improve the energy efficiency of the building without invasive and intrusive intervention. These solutions are already being explored in a number of pilot projects [11].

These considerations are always related to the specific building (affected by the shape, volume, orientation) and by the climate where it lies. Studying the environmental qualities of historical architecture, the bio-climatic features and the climatic qualities of the site can be an important starting point for an energy refurbishment project aimed at facilitating energy savings in a building. In fact, improving the well-being and sanitary conditions of these buildings represents an opportunity for reconsidering "tradition", by adopting an analytic and critical outlook of the capacity expressed by the historical building in solving the microclimatic problems.

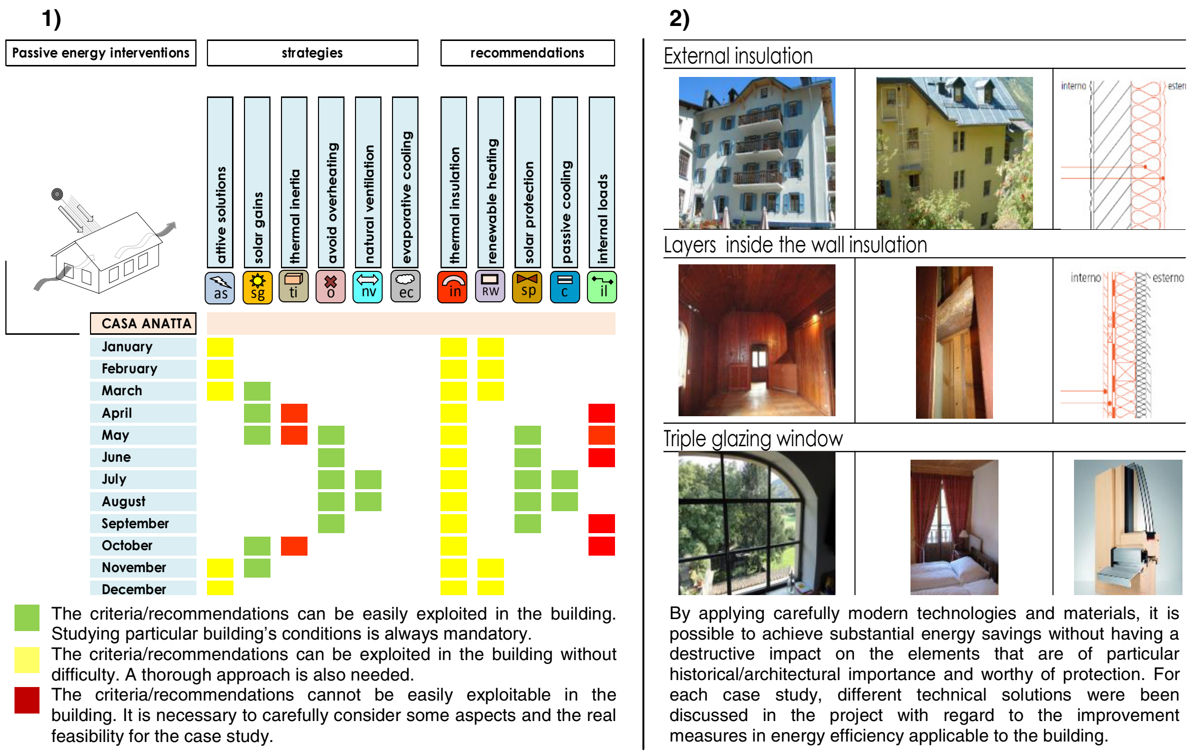

Fig. 5. Example of two working tables generated during the second step of the project, project proposal definition to enhance the energy balance of the heritage buildings studied, as part the overall system of charts proposed: (1) The matrix represents all the possible type of passive intervention to optimize the energy efficiency of the building; (2) An example of possible solutions analysed for each case studio in the project with regard to the improvement measures applicable to the building envelop.

According to the features of each historical artifact, preference will be given to the feasibility of the solution, compatibility with and respect for historical features, reversibility, energy benefits, the environmental impact and the future administration/maintenance and conservation aspects. Furthermore, energy efficiency improvement measures by renovation/restoration or rehabilitation of these older buildings are aimed at maintaining and protecting the original architectural features reinforcing the historic character, increasing property values avoiding degradation.

The final energy balance "*post operam*" is compared with the initial situation so the benefits obtained can be checked immediately. The final scoring system makes it possible to evaluate the all parameters considered as fundamental on historical structures; parameters that can be used to evaluate subsequent solutions. The decision-making process can therefore be executed in function not only with the final rating, but also in function with each criterion analyzed.

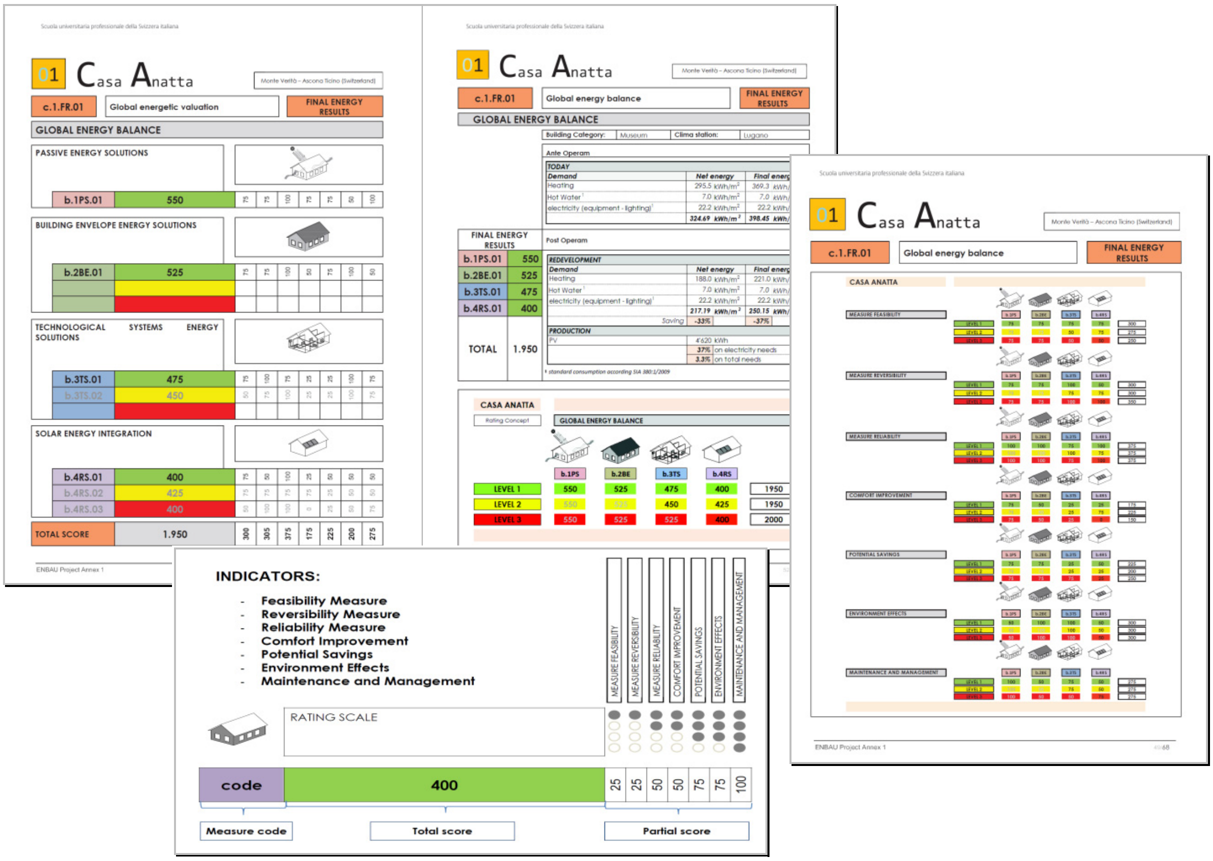

Fig. 6. Global energy assessment chart (third step c). This chart summarizes all the proposed solutions and allows a tangible and clear overview of the benefits brought to the building by the proposed solutions.

5. Solar energy resources

When dealing with the use and the installation of Solar Energy Systems (Photovoltaic and Solar Thermal) in the built environment there are preservation problems, which very often are ignored by installers and enterprises that look at the cheapest and most effective solution. The existing housing stock is very heterogeneous. Constructions have to fulfill not only different needs and they can be categorized also according to building techniques, year of construction, materials, components, representative status and, of course, architectural quality. This project demonstrates that respect for historical heritage, protection of the landscape and the employment of renewable energy can and must be conciliated, especially in specific contexts like historical protected buildings.

In order to prevent an indiscriminate and uncontrolled use of solar technologies and, at the same time, to invest economic and space resources in the most effective possible way, it is necessary to find a proper balance, or compromise, between technical and aesthetic requirements. High architectural design quality for Building integrate PV (BiPV) or Solar thermal is almost necessary as demonstrate in past experiences [12]. Today a number of innovative and advanced products for building integration that can be used in sensitive built environment are present on the market. But unfortunately, on one side, technicians are not aware about the points of preservation; on the other hand officials who are responsible for preservation ignore the possibilities that solar energy and solar products offer. Integrating renewable technologies into an urban context, or into existing buildings, can improve the architectural and technical quality of the building in terms of economic and environmental sustainability. Scenic parameters that perhaps currently prevent the use of these technologies in towns and in historical downtowns mean that the owners of this category of property cannot exploit these benefits. One of the objectives of this project was to identify appropriate technical solutions for different situations and in terms of reduced impact that's requires careful study, particularly in the case of historical buildings.

By using the same *color codes* (*green:* solution easily exploit in the building; *yellow:* if can be exploited in the building without difficulty; *red:* solution that cannot be easily exploitable in the building) and *score system* previously reported, different solar technologies have been assessed in the project (as an example, see Fig. 7). A series of architectural and scenic evaluation criteria (*co-planarity; respect of the lines; shape; grouping; accuracy and visibility*) related to the installation of solar and photovoltaic panels were applied to each particular case study in order to establish recommendations and appropriate solutions in accordance with the feasibility of the proposed measure and to define the constraints making a negative impact on the solar installation in historic buildings by considering also how renewable energy integration is perceived (*level of acceptability*).

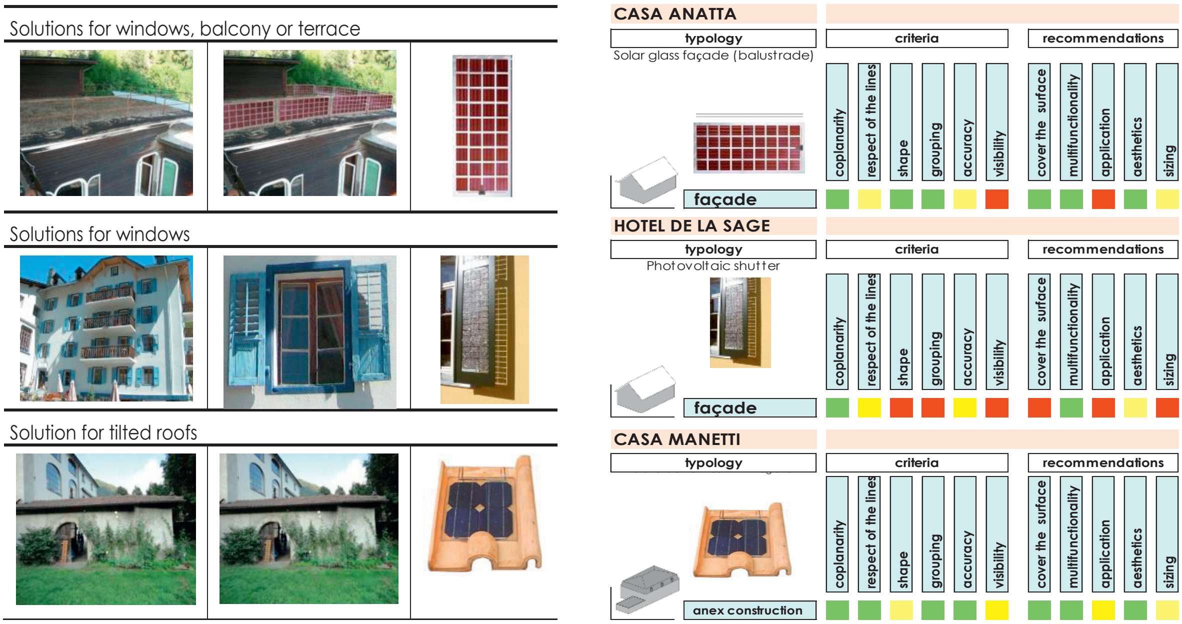

Fig. 7. Some PV solutions explored in the project to be undertaken in the case study building.

6. Outcomes and further developments

The methodology developed in this project considers a global energy concept that examines the aspects linked closely to the climate and the site, as well as those tied to the building itself and to its unique features, and that proportions a useful instrument for the decision-making process, based on different multi-criteria that will help identify the potential strategies for the renovation/reconstruction or energy redevelopment of historical buildings belonging to our cultural heritage. Furthermore, the proposed methodology has highlighted that even small interventions can give important results in the comfort improvement and in the reduction of energy consumption in this type of buildings.

This project represents a great opportunity to evaluate the integration of new construction systems and solar components, based in previous experiences to achieve the objectives of energy efficiency and reducing environmental impact. The rating scores criteria established, evaluates the retrofitting measures' performance for each case study and allows to highlight the most important aspects relating needs and constrains for better implement new solutions to improve building energy performance and solar energy integration. A close collaboration between all project participants and stakeholders was been the basis for the successful development of the proposed methodology. The most important factor involves the development of a methodological approach that is generic but applied to the individual case studies, based on easily interpreted charts that can be used to identify the main parameters on which to work, and a set of different solutions that can be selected depending on the execution possibilities. This system provide valid assistance in both, the earlier decision-making phases and also once the solutions have been implemented, when they act as a tracing and recording control tool that enriches the database of this type of building. Project outcomes have been to define a series of interventions, single or cumulative, that will be of unquestionable interest to the client and the designer, but also to the local bodies, Cultural Heritage offices and the community, since it will be an example of good practice to contribute to global environmental sustainability. Further development would be the implementation of the achievement results to a “web” digital tool based in an existing software tool useful to identify the potential strategies for energy refurbishment in historical buildings [13].

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