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Supplying historic buildings with energy, without impinging on their historic and cultural values

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Abstract

The Venetian Villas are an historic body of 3782 buildings in Veneto and Friuli from the XVI century to the XVIII century. UNESCO has certified 24 villas of Andrea Palladio as World Heritage Sites. The Regional Institute for the protection of these sites has launched a competition to find innovative technological solutions that contribute to the energy needs of the villas without interfering with the architectural and landscape quality of the same. The paper illustrates the technological solution that won the competition.

The possibility of powering the historical Venetian Villas with renewable energy sources is explored. The realization of submerged PV plants integrated with existing water basin is suggested as the best solution . Energy yield is adequate and landscape quality is conserved. Technical details and architectural layouts are discussed.

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1. Introduction

In Italy, and more generally in Europe, there is the problem of how to introduce technological innovations that provide energy contributions from renewable sources, within areas of cultural interest and landscape protection [1], [2].

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The case of the Venetian Villas (built by the Venetian nobility mainly between the XVI and XVIII centuries) is a good example; they constitute a vast heritage (3782 villas have been catalogued between Veneto and Friuli) partly public, but mostly private and predominantly characterized by high conservation and management costs. [3], [4]

First of all, it is important to create conditions of use appropriate to present times, in particular for internal environmental comfort and to bear in mind that their usability today (in a completely different context from the original) is a guarantee for their conservation. But the main difficulty lies in introducing a high fruition quality without damaging the historical consistency of architectural and artistic artefacts. The problem originated more than a century ago, when technological developments emerging at the turn of the XIX century offered the opportunity to introduce substantial improvements to the comfort of buildings through sanitation, electrical appliances, heating and transport, that is, bathrooms, lighting, radiators and elevators. Although these improvements were easily introduced to new buildings, they caused a trauma in those pre-existing, and in particular in all the historic buildings of cultural value,.

It is well known that these events affected both Venetian Villas and, in general, the whole historic heritage. Things are further complicated where this heritage has been reused as public venues, such as museums or cultural centers, where measures of accessibility, safety, escape routes etc. have generated further problems.

The last potentially looming trauma concerns the introduction of renewable energy plants to supply electricity or heating to historic buildings. These are generally energy-intensive plants, because of their intrinsic characteristics and the fact that it is almost impossible to limit energy consumption, since the dispersing surfaces cannot be modified. Therefore energy procurement becomes strategic in the reduction of management budgets.

Several studies have been carried out in Europe [5] , [6] and in the USA [7] about PV integration in historic buildings but the Venetian Villas require a very specific approach; for these reasons we propose a new original idea: SP2 (Submerged Photovoltaic Solar Panels)

In Italy, interventions on the historical heritage are under the control of the Ministry of Cultural Heritage and Tourism, which has published, among other things, "Guidelines for improving energy efficiency in cultural heritage" [8]. These guidelines are aimed at preserving the architecture from any tampering that would alter their characteristics and value. In the review of technological innovations covered in this paper, the technologies for protecting buildings, such as films on windows glasses and heat pumps, are few and somewhat inconclusive. The submerged PV technique is unknown since it is an unprecedented breakthrough.

This solution is based on the following items:

1. Water strongly absorbs the infrared part of solar radiation but slightly affects the visible part which is the important component used by commercial PV modules
2. Large water basins are available in many parks of Villas
3. Submerged modules are not visible so that the landscape is not modified
4. Solare energy harvesting is adequate for the Villa energetic needs if equipped by a suitable energy storage systems and modern heating and lighting facilities.

2. “Bodies of water”

Fig. 1 Villa Pisani at Stra (Venice).

The public institute responsible for the protection of Ville (Istituto Regionale per le Ville Venete – IRVV) has addressed this issue in the most logical way, launching a challenge to the world of researchers and professionals as a competition of ideas. The call for tenders "Designing efficient restoration - Technological innovation at the service of the Venetian Villas" has been published and restoration projects are expected whose technological features satisfy the following criteria:

- to guarantee high performance with reduced consumption of primary energy, minimizing the emissions into the environment;
- to incorporate the use of renewable energies, satisfying real sustainability and feasibility criteria.

In practice, the Regional Institute is asking the professionals for innovative solutions that supply the Ville with energy, without affecting their architectural and landscape appearance.

For new buildings this isn’t a problem; photovoltaic panels, for example, are easily integrated into roof covering and cladding, but this is not allowed in heritage setting.

The call provides: an award ceremony (1st, 2nd and 3rd prizes) for the solution on the general theme of the villas and a special prize for the specific solution applied to Villa Venier Contarini, headquarters of the Institute (IRVV). The authoritative jury will award the first prize to the proposal known as "bodies of water" and the special prize also to "bodies of water" ex-aequo with other proposals.

The idea of a "body of water" is a seemingly simple solution. However, it has a complex background, as often happens for nnovations with a strong decisive character. The proponent team[1] includes specialists who had already

[1] The team includes specialists who had already addressed these topics separately: Cristian Bomba (architect, president ITEB Ltd. (Spin-off of the University of Chieti), team leader), Carmine Falasca (Professor of Architectural Technology, University of Chieti office in Pescara, led experiences of restoration and reuse of historic buildings), Giorgio Garau (Professor of Technological design Architecture, University of Padova, has conducted research on the introduction of new technologies into historic buildings), Sergio Montelpare (Professor of Physics Environmental technology, University of Chieti office in Pescara, has conducted research on the energy behavior of buildings), Marco Rosa-Clot (Professor of Nuclear Physics, University of Florence, has been conducting research on energy capture technologies using floating and submerged PV), Federico Saccarola (construction civil engineer, has conducted experiments in the field of energy in buildings).

addressed these topics separately: Cristian Bomba, Falasca Carmine, Giorgio Garau, Sergio Montelpare, Marco Rosa-Clot, Federico Saccarola. However, the opportunity of this call has allowed the team to find a synthesis that comes from careful observation of the landscape of the most important and representative Venetian villas: Villa Pisani at Stra (see Fig. 1), very close to Padova, but in province of Venice.

Whoever, starting from Padua, begins to walk along the Brenta coastline towards Venice (formerly a bustling waterway between the two cities) encounters a majestic complex (called the queen of the Venetian villas) built by the Pisani family starting from 1721. The most illustrious member of the family, Alvise Pisani (1664-1741), was ambassador to the court of Louis XIV and later Doge in 1735.

The Villa was state property and now it is a National Museum. It has a complex floor plan characterized by a plurality of elements and dominated by the axis which connects the main building to the scenic backdrop of the building of the stables. This axis is emphasized by the long water channel that completes the eighteenth-century structure in its scenic and landscape layout. Surprisingly, we discover that the water feature wasn't created as a part of the landscape, but as a scientific instrument. Indeed, it was built in 1911 by the University of Padua as a laboratory for hydraulic tests.

This curious story leads to what summarized above. The presence of bodies of water in the Venetian Villas is widespread, but it never has a decorative or scenografic origin. At the base there is always a utilitarian reason, such as in the case of the fishponds[1]. One aspect however is also the microclimate utilitarian function of the bodies of water; the water, always flowing, introduces a not negligible heat mitigation during a hot summer. As recent studies of environmental physics have shown, in summer time buildings benefit from the comforts induced by the presence of greenery and water in their immediate surroundings.

This last point leads us to consider the presence of water as a factor which is and can always be involved in energy issues. Hence the idea to equip the villas with photovoltaic submerged systems: a solution which has already been studied for other situations. In existing water bodies it will be sufficient to immerse the panels to a depth of 10 cm. The immersion will prevent the new technological apparatus to impinge on the landscape.

3. Submerged PV modules

The energy produced by a PV modules submerged of few centimeters in a water body is equal to that of a normal photovoltaic system placed on the ground or on a south-oriented roof. In fact the lower energy collection due to the panels being placed horizontal is compensated by the greater efficiency of the panels which are kept at low temperature by the water layer that covers them.

This effect is illustrated in the graphs presented below (see Fig. 2) shows the values of measurements made with panels immersed in water at different depths (4 and 40 cm, respectively) with respect to a panel exposed to the air [9] and [10]. .; (b) gives the theoretical value calculated for panels of different structure (monocrystalline silicon, polycrystalline silicon and amorphous silicon) that can be used in this system [11]. These data are compared with the estimates for panels of one kW placed at various degrees of tilt, as given in. The yellow dot represents our operating conditions: flat panels and active cooling.

As we can see, this system reaches approximately the same collection efficiency of a normal ground plant (about 1300 kWh / year per each kWp installed). It should be noted that the latter, with the same power, would occupy an approximately double area (see Fig.3).

The advantage of this solution is easily recognized when the body of water is already present, as is the case in the two examples entered in the competition boards, the Villa Pisani at Stra and the Barbarigo Villa at Valsanzibio in the province of Padua (see Fig. 4).

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[1] Notice how the Venetian villa is based on a utilitarian concept: it is a building designed for the supervision and management of the attached agricultural farm.

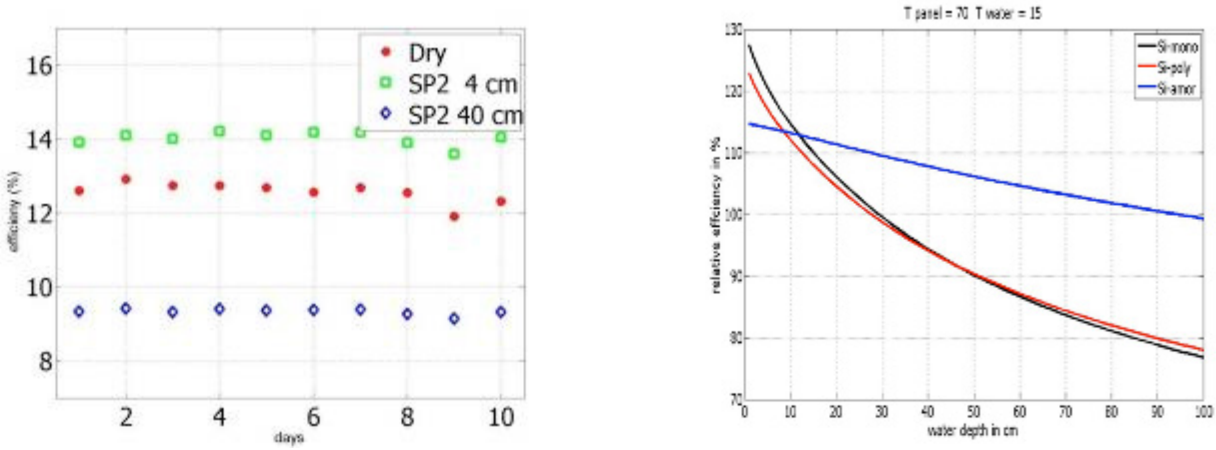

Fig. 2 (a) measured efficiency of a PV panel in the air (dry), surrounded with 4 r cm of water (SP2 4cm) and 40 cm.; (b) efficiency of PV panels according to depth.

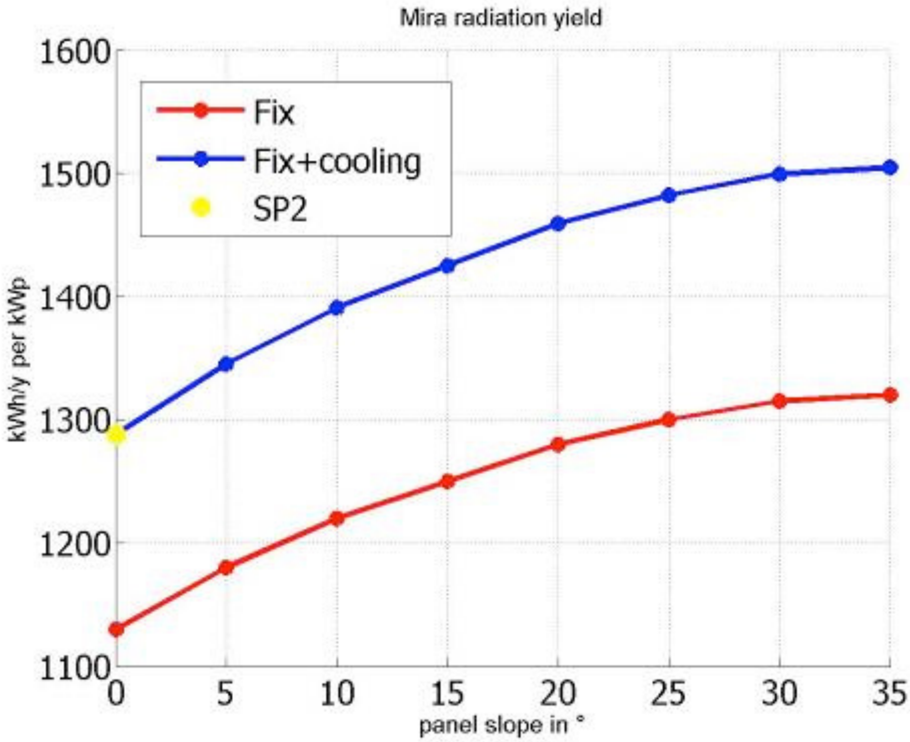

Fig. 3 . Energy yield per year per kWp versus panel slope;

In the last years several works have been published about the advantages of using submerged panels; see for example references [12] and [13]

The solution is feasible in all the cases where bodies of water are present, which happens not only in the group of ancient Venetian villas but also in other historic buildings in Italy and in Europe.

And where there is no water?

In this case it is possible to build a new body of water like for example, in Villa Emo at Fanzolo (Treviso). As evidenced by the story of Villa Pisani, the inclusion is an act of design that works well within the structural logic of the landscape and cannot be perceived as improper intrusion. In Villa Emo (see Fig.5a and 5b) it looks as if the landscape itself is designed for this; water is simply a substance replacing grass inside a pre-existing lawn.

Fig. 4 Villa Barbarigo at Valsanzibio.

Fig. 5 (a) Villa Emo at Fanzolo (Treviso); (b) Villa Emo at Fanzolo. New pool in place of the strip of grass.

4. The Villa Venier-Contarini project

Fig. 6 (a) Villa Venier Contarini, Mira (Venezia); (b) new pool geometry; (c) new pool.

For Villa Venier Contarini (home to IRVV) the call requires a specific project. In the villa park, the old "lake" has been lost, as is apparent from the description that makes the card of IRVV catalog.

The inclusion of a new pool is based on the following criteria:

- It does not substitute the lost historic element, "a lake", but it is clearly a new element in order to not create ambiguities of historical interpretation;
- It proposes a historic landscape approach, at least as it concerns its inclusion;
- It is inspired by the model of a long and narrow pool in the axial position relatively to the body of the building;
- It doesn’t take as a reference the main building, but the guest house (east side barn): thus the body of water is inserted in the parterre (without touching the grove) and is equidistant from the shadows cast to the east (annexes) and west (grove);
- it fits asymmetrically in relation to the central body, thereby accepting the asymmetric setting of the park and the not-unified conformation of the villa architecture;

The transfer of these criteria to the project uses a typical method of ancient architectural culture, which aims to create architectural or landscaping objects based on a geometric construction reflecting the relation of order between the parts and their dimensions (see Fig.6a, 6b and 6c).

Landscape impact of the new pool: the images show how the new presence enhances the empty space between the grove and the attached bodies. The image (see Fig. c), which has the guest house of the villa as its background, is penalized by the fact that the guest house is still in a state of pre-restoration. Technological sections (see Fig. 7 and **Error! Reference source not found.**8) refer to the PV array placement in the pool of the new plant. The intervention is removable and completely reversible.

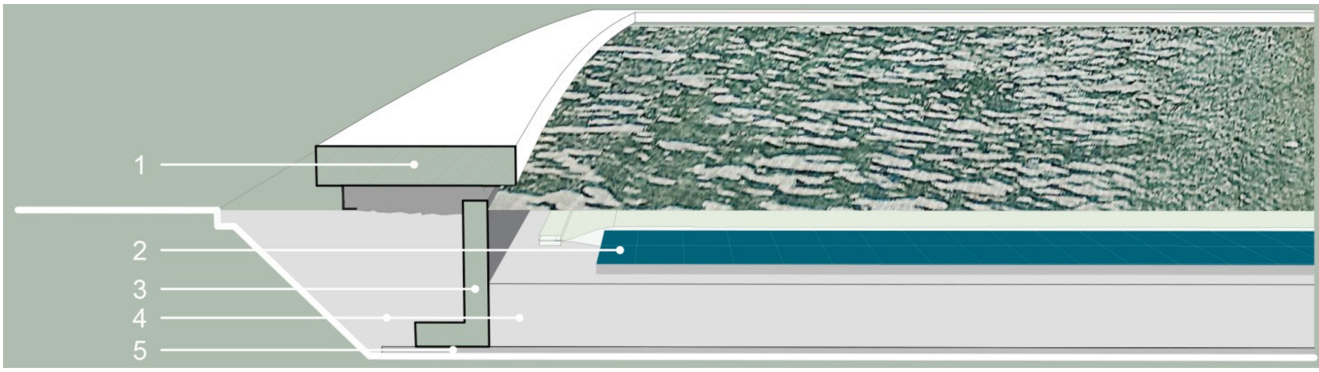

Fig. 7 Details of the pool: 1) Istrian stone, 2) photovoltaic panel, 3) prefabricated curb, 4) compacted gravel, 5) Bentonite needled cloth.

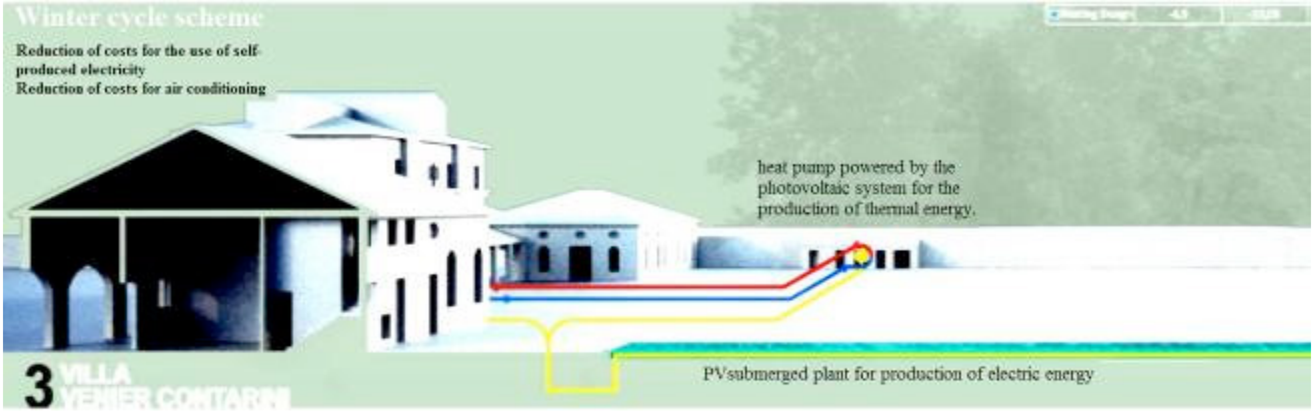

Fig. 8 Winter energy cycle scheme.

5. The energy yield and the system solution for the villa energetic needs

5.1- Energy analysis and plants

The plots below show the development of energy consumption in the two situations: present state and the state of the project.

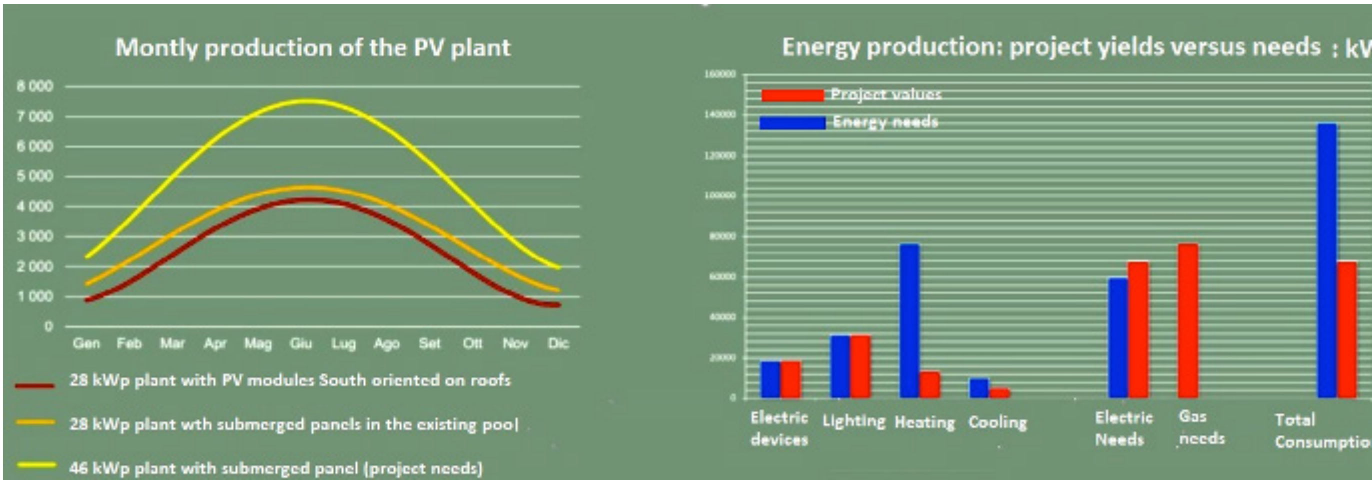

Fig. 9 Energy budget for Villa Venier.

The latter includes

- New body of water with the photovoltaic field (complete with plant for mechanical filtration and UV-C);
- electric energy storage system (batteries in the current technical status);
- heat pumps and buffers (which replace the function of the cooling unit and of the gas boiler);

Due to the increase of the power consumption for the presence of the heat pump (which completely replace the gas burner) a photovoltaic system with storage batteries has been provided. The latter is dimensioned as follows:

- Installed power 46 kWp;
- No. 145 panels arranged in 29 rows of 5 panels each

The energy produced by this system is 67,500 kWh / year on average, enough for the needs of the Villa.
The solution is therefore able to ensure reduced consumption of primary energy while minimizing the emissions into the environment. This allows the use of renewable energy according to sustainability criteria
(see Fig. 9 for energy budget for Villa Venier) . Values for the second plot in figure 10 are given in table below:

Table 1: values for energy budget.

	Electric devices	Lighting	Heating	Cooling	Electric Consumption	Gas consumption	Total
	kwh	kwh	kwh	kwh	kwh	kwh	kwh
Project values	18,345	31,173	13,213	4,757	67,489	0	67,489
Energy needs	18,345	31,173	76,434	10,060	59,578	76,814	135,992

Fig. 30 Thermal balance for Villa Venier.

5.2- The system solution for the needs of the villa

The study of the energy requirement of the main building of Villa Venier was performed using the Energy Plus calculation code. The analysis of the plans highlighted a wall thickness of about 28-30 cm., assuming according to the existing literature a wall composed of full bricks with two heads and plaster on both sides. We assumed single-glazed windows with heat exchange coefficient U equal to 5:56 [W / m2 K] for those with transom and 3.69 [W / m2 K] for the double ones. As regards the plants, we assumed the characteristics of systems currently present and in particular: – boilers with heat input min / max 81/115 [kW], thermal output yield min / max 75 / 105.3 [kW], average profit yield of 92% and maximum operating temperature of 97 [° C]; – air-cooled water chiller with centrifugal fans, with R407C; cooling capacity 62 [kW], power absorbed by the 24 [kW] compressor, total absorbed power 28 [kW], COP 2.21.

Energy simulations were carried out both in the condition of "status quo", according to the systems described above and using the currently present fan coils, and in the conditions of "state of the project", in which the same fan coils have been interlocked by a plant system to the heat pump. The first solution suggested for the heat pump is of the water / water type with geothermal "sub-surface", but given the need to contain costs it may be better the use of air/water heat pumps. To this purpose, in order to highlight the benefits of a heat pump system without limiting the design choices to the geothermal system, our energy simulations assumed coefficients of performance in heating and cooling of 4.8, i.e. values easily obtained from both types of plant. From the analysis of the output data (see Tab. 3) major losses, as easily estimated, happen through the walls and windows. A significant component is represented by the obligatory change of air according to the use of the building which was assumed to be "office" for all the rooms.

As regards the summer thermal project, the analysis of thermal loads (such as irradiation) takes into account the increase induced by energy contributions (such as occupants and equipment) and the natural increase due to the final use (offices). From energy simulation we get a cooling heat requirement of approximately 70 [kW].

The solution with a heat pump allows a reduction of the primary energy requirement of about 50%; the greater increase takes place for the heating phase, as it changes to a system with energy efficiency almost 5 times higher.

When increasing the power consumption due to the presence of the heat pump (which however completely brings the gas consumption to zero) it is necessary to provide the villa with the photovoltaic plant.

The energy produced by this system is 67,500 kWh / year on average (5% fluctuations from year to year are normal) and so it would be quite sufficient for the needs of the villa. However this energy is delivered irregularly and in particular only during the sunny hours and with a strong variability between summer and winter. It is therefore essential to think of an energy storage system that allows a delayed use of energy during the hours when there is no sunlight.

These systems exist and are of different types. The battery system for storing PV energy is now commercial and several companies produce stack batteries directly integrated and sized for the PV system. This is the solution adopted in the proposal. A more efficient alternative are the flywheels that, as it is well known, have had a limited market share and only now are appearing on the market. The advantages are in the system duration (the typical life expectancy is 25 years) and in the high efficiency (over 90% of the energy is returned to the user at the point of use) however, the costs are higher.

An energy storage system based on batteries or flywheels can make the Villa energetically self-sufficient for over 80% of its energy needs. The national grid would be used only as a partial supplier of energy during the winter months when energy collection is insufficient.

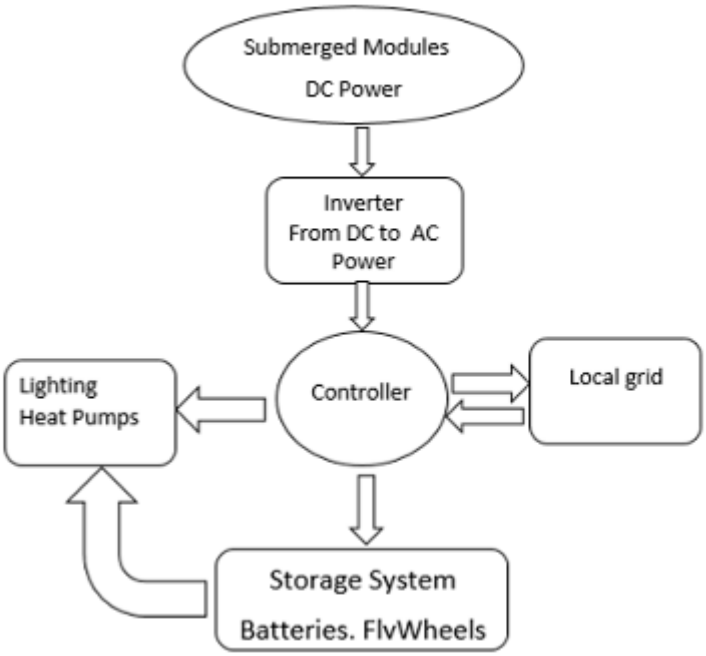

Fig. 11 Block diagram for the energy fluxes

The proposed system is stand alone: the energy is mainly used for the Villa needs and the grid would automatically be used only as a supplier in the presence of an energy deficit.

6. Conclusions

The result of simulations and architect drawings have shown that the proposed solution is able to reconcile the two seemingly opposite aspects of the problem, i.e. procurement of energy and minimum environmental and landscape impact of technology. The solution is viable both for Villas already provided with water pools and for those in which the body of water has to be added. The energy contribution is correctly dimensioned respect to the Villa energy needs and the visual impact negligible.

The technology however has been proved only at the laboratory level and an experimentation on a full scale is necessary. Due to the decreasing costs of the PV modulus and inverter, and due to the availability of already existing water surfaces, the investment necessary should be limited and the results certain.

We hope in the next future to be able to produce experimental results for a Venetian Villa!

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