A Systemic Approach for Preliminary Proposals of Sustainable Retrofit in Historic Settlements. The Case Study of Villages Hit by Earthquake

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Abstract

A proper and innovative restoration and regeneration programme of historic settlements affected by earthquakes can be an opportunity for their most effective use and a more attractive new function. The paper presents the results of two studies that Architettura>Energia Research Centre of the Department of Architecture of Ferrara accomplished for Public Administrations as instrument for sustainable reconstructive interventions in areas with very complex environmental, social, economic and historic aspects.
The two locations considered are Caporciano, a small town within the area around L'Aquila struck by the earthquake in 2009 and now only partially inhabited; and Apice Vecchia, near Benevento, damaged by two earthquakes in 1962 and 1980, which forced the population to settle a new town in the vicinity.
The proposed procedure is structured into two phases. The first consists of a preliminary on-site survey aimed at simplifying the acquisition of a large amount of data, which will facilitate a subsequent in depth survey focused on the energy and environmental characteristics of the towns. Data are analysed after the survey to establish dimensional parameters useful for energy simulation and for setting-up a database of building technologies and materials, used to calculate the energy performance index of the envelope for the current winter heating and summer cooling of the towns. During the second phase of the study, intervention strategies are developed to improve energy and environmental conditions of the urban system, depending on residual performance of technical elements, building's function, historic value and earthquake damage.
The proposed intervention scenarios are contextualized through the application of the strategies to specific buildings used as case studies, which are useful to validate the procedures for retrofitting the building and the hypothesis of restoring historic settlements.

Keywords: Preliminary audit, energy retrofit, environmental quality, historic settlement, seismic damages.

1. Programming tools for supporting local policies

At a time like the present, where the construction sector is hit by a severe crisis, refurbishment and conversion action of existing buildings have a strategic role to promote recovery. To make stable and to implement this trend, it is inevitable that Local Authorities should introduce incentive aimed at regenerating urban centres. This need is even more urgent in the case of territories in which economic and social decay adds to the earthquake’s devastating effects, accelerating depopulation and only residential use. The promotion of wide recovery action requires a preliminary feasibility study to provide the data needed to correctly address the programming tools (rules and regulations, calls for encouraging private initiative, guidelines, etc.) and to optimize limited financial resources, often made ineffective by the uncertainty of long and complex processes. Given that, the analysis of the actual energy behaviour, an essential component for a correct evaluation of building’s residual performance, must be fast, enough reliable and economically inexpensive in the very first phase of the process.

The results of the research, documented in this paper, wants to answer to these needs through a simplified, but reliable and effective procedure applied to the case studies of 2 small historical villages, located in the South-Italian Apennines, that gave a significant feedback on the methods and tools adopted.

The first case study of Caporciano[1] (2010) fed the second of Apice Vecchia[2] (2012) in a diachronic synergy. Both concern an urban matrix strongly hit by earthquake, respectively:

- in the Navelli plateau in the Abruzzo region, within the crater generated by the 2009 earthquake near L’Aquila where winter conditions are very hard;

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[1] Design research by Faculty and Department of Architecture of Ferrara, Architettura>Energia Research Centre with IUAV University of Venice. Coordinator: Prof. P. Davoli. Tutor: Dr. V. Belpoliti, Dr. P. Boarin, Dr. M. Calzolari, Dr. R. Reitano (IUAV). Students: F. Abenante, M. Bortoloni, V. Farinelli, D. Marcucci, L. Nadalin. Design Workshop ‘Idee e proposte ecosostenibili per i territori del sisma aquilano”, Pescara – Caporciano, 2010. Organization: DiTAC – UNICH and SITdA. Coordination: Prof. M. C. Forlani and Prof. G. Eusani.

[2] “Integrated study for the definition of design strategies aimed at energy and environmental refurbishment, renewable source-fed plants integration and preliminary geological survey in the historic settlement of Apice Vecchia”, research commissioned by the Municipality to the Architettura>Energia Research Centre. General Referees: Prof. P. Davoli, Prof. A. Rinaldi, Prof. G. Bizzarri, Prof. R. Caputo. General Coordinator: Dr. P. Boarin. UNIT 1 - Architettura>Energia Research Centre working group. Scientific Referees: Prof. P. Davoli, Prof. A. Rinaldi, Prof. G. Bizzarri. Economic evaluation Referee: Prof. L. Gabrielli. Team: Dr. V. Belpoliti, Dr. P. Boarin, Dr. M. Calzolari, Dr. V. Farinelli. UNIT 2 - Department of Earth Science. Scientific Referee and working group Coordinator: Prof. R. Caputo. Team: Dr. Geol. N. Abu-Zeid, Dr. S. Bignardi.

- in the area near Benevento, within the seismic activities that hit the south of Italy between 1962 and 1980, regions where the summer comfort is very difficult to reach.

Both case studies aim at a sustainable recovery and the seism can be interpreted as an opportunity to enhance energy and environmental conditions of the whole building system.

Both aggregates are typically rural-origined, made with techniques and technologies result of a spontaneous and non-coded practice mainly "pre-industrial", which uses materials that can be found mostly at the local scale. The on-site survey showed that, as it is common for spontaneous architecture and historical buildings, the building fabric has its own predisposition to passive control of external environmental stresses both at the urban scale and at individual buildings scale. This environmental management skill (which we may call "environmental metabolism") can be found through a critical reading of the features of the historic town.

2. The town and the earthquake

2.1. Caporciano

The small historical town has started to move away even before the earthquake (which has further exacerbated an already critical situation), because of a declining economy that was no longer able to catalyse the interests of local entrepreneurs. The urban grid is characteristic of an historical aggregate with two or three stories terraced buildings. It is almost entirely a residential village, where just over a third of housing is permanently occupied and the remaining two-thirds are made up of second homes or empty buildings because of the damage caused by the earthquake.

Since the earthquake was a vibrating type, the greatest damage have been reported from the floors and roofing, while the lesions are less evident on the external walls, with the exception of a few cases. The initial embarrassment in proposing solutions for energy efficiency and environmental sustainability within a territory dramatically affected by the disaster and often with very different objectives priority has soon vanished when people understood the extreme need for planning to feed the prospects for revival of these economic and social realities in deep crisis.

The study, called "climate village", provided the development of strategies for raising the energy performance of the entire urban aggregate, according to the different degrees of intervention possible on individual buildings and the needs of recovery, consolidation and new functions.

Figure 1. Views of the medieval village of Caporciano. The aggregate consists of approximately 300 buildings, with its traditional architecture of rural type, consisting mainly of vertical walls (coinciding with the elevated structure) in local stone, with rustication and gravel of various sizes, which can reach 90-100 cm thick, even with small-recovered brick elements. The village has an outer belt of expansion characterized by newer buildings (from the 50s onwards), with concrete-frame technology and plugging in semi-solid blocks of brick or masonry bearing.

2.2. Apice Vecchia

The country is now completely deserted because of the substantial structural damage caused by strong earthquakes that hit the area generating a high level of critical issues for the safety of citizens, so that the Local Administration decided to move the community, founding a new town a few miles away, on the overlooking hilltop. The strong link with the cultural roots and the desire to enhance the historic building heritage have prompted the City Council of Apice to take the road of recovery and redevelopment of the town with the purpose of hosting new functions that can trigger a new life cycle for the village itself.

Sitting on the top of a hill, the small urban aggregate, plausibly founded by the Romans, but with a significant development during the Middle Ages and during the Norman period as well as in the Renaissance period, has a very compact urban morphology, although slight differences in the building plot which declare a progressive development over the centuries. The village is made up of buildings of small sizes (even one or two cells per unit) with two floors above ground, mainly placed close to the slope. These buildings housed laboratories or small shelters for farm animals in the lower levels. In the Northern part of the village stands the castle, surrounded by the buildings of the wealthiest families, while in the central portion between the two ends stand the building units with the easiest features. Aggregated into arrays with very large blocks that make up for the total development of the village, the buildings are mostly overlooking the front street or, in some cases, towards the inner gardens.

Figure 2. Views of the streets of Apice Vecchia. The reduced ratio between the width of the road and the height of the front allows to have paths and facades heavily shaded; the presence of vegetation in the interior gardens provides greater air oxygenation and humidification, since these characteristics in summer passively contribute to the protection from overheating. The vertical closures are largely made up of dry masonry facings with hewn stone and fill with stones weakly bound with lime and sand, or from mixed masonry of stone and brick, possibly recovered by the demolition of other buildings, also for the variant with brick elements with regular lists.

3. A systemic approach to historic towns refurbishment

In the small towns studied (although many considerations can be easily extended to the whole system of settlements with relevant testimonial value) the need to tackle the knowledge process and the definition of requalification strategies in a systemic and integrated way appeared immediately clear, shifting the focus from the single building to the urban scale. Exceeding the logic, however valid, but no longer sufficient, of enhancing environmental performance of each building, it is possible to support the whole urban performance control and the following effects on the environmental conditions of outdoor public and private spaces for the community. This perspective allows to successfully deal with the issue of high standards, even in historic contexts, as required by European directives on the energy performance of buildings, where the application of the model of 'nearly zero energy building' is suggested, even in case of existing buildings' major renovations when they are «technically, functionally and economically feasible» (Directive 2010/31/EU).

It is clear that this approach should coincide with the need to protect the building and its historical identity, especially when under conservation constraints. To ensure this, the systemic approach adopted in the research allows, through the control of the whole urban virtuosity, to act in a different and compatible way with the single buildings, while significantly reducing overall global energy losses, with the aim of a compensation between buildings with different historic features.

4. Methodology

4.1. Simple procedures for survey and energy audit aimed at understanding the ancient town

Given the preliminary nature of the studies and the high number of buildings to be investigated for each village[3], it was considered appropriate to proceed in both cases with a first phase of "fast" survey to be done in short times (1-2 days with a working group from 4 to 8 units), able to simplify the acquisition of a consistent amount of information. The optimized procedure needed to program in advance all data to be collected in the field that have been chosen from those most able to influence the global energy and environmental behaviour, considering the characteristics of the historic environment, the elements with morphological connotation and documentary value, as well as the role of some elements of passive conditioning and the presence of visible damages caused by the earthquake. This system is able to return the technological and energy characteristics of the surveyed buildings, through a user-friendly tool used directly in the field even by unskilled personnel, through a portable device (smart phone or tablet) with specific applications.

For each surveyed building the following information were gathered:

- the period of construction (in relation to time bands previously encoded and related to the significant moments of technological development);
- the intended use (residential, commercial/industrial, mixed, other);
- the number of habitable floors;
- the presence of elements of historical and artistic value on masonry (mouldings, decorations around doors or windows and other significant elements to be preserved);
- the building type (terraced or semidetached);
- the type of structural system (load bearing walls or pillars);
- the colour of the wall (light, medium or dark);
- the presence of mitigation bioclimatic areas (lower or upper buffers);
- the presence of important thermal bridges (external faces, porches, balconies or loggias, etc.);
- building technologies and materials of the opaque vertical closures;
- transparent vertical closures technologies (vertical window frames), if present;

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[3] For Caporciano 106 out of 286 buildings, equivalent to 37%. For Apice Vecchia 233 out of 313 buildings, equivalent to 74.5%.

- building technologies and materials of top closures, highlighting the presence of ceilings;
- the type of upper closure (pitched or flat);
- the presence of damage caused by the earthquake (low, in case of minor injuries or cracks, medium, in case of small collapses, or high, if in the presence of collapsing floors or roofs);
- the type of winter conditioning, if present;
- additional factors that are important for assessing energy and environment behaviour, like any upper floors or the presence of non-homogeneous material elements in the walls (i.e. the existence of scaffolding holes).

4.2. Parameterization of the surveyed data and definition of benchmarks and calculation of the overall energy performance

Energy analysis on the data carried out after the on-field survey were conducted using a parametric evaluation methodology resulting from the experience of the bottom-up analysis. This method, already used in the analysis of urban aggregates, consist in the acquisition of a certain number of benchmark data resulting from analysis carried out on a sample of buildings representative of the entire built environment. Subsequently, these data are parameterized basing on the characteristics of each building (according to typological, technological and dimensional parameters) to obtain the indicator of the actual energy performance. This method helps to simplify the complex analytical process required to assess the energy performance of buildings, making possible a simplified and fast analysis of entire urban clusters and ensuring a final value of $EP_{i,invol}$[4], $EP_{e,invol}$[5] and/or EP_{gl}[6] of each single building. For the compilation of this data, Caporciano and Apice Vecchia differ in the presence in the first context of the winter heating systems, completely absent in the second due to the depopulation resulting from the earthquake of 1962.

Underlying the process of simplification of the calculation method there is, as already mentioned, the determination of some benchmark data to be extended to all buildings in the village. To obtain such data analysis, a detailed energy assessment was done on some models (basing on UNI TS 11300-1:2008), built to describe the typological, technological and dimensional features of the most common buildings in the village, in reference to the following factors:

- building type: terraced houses, semi-detached houses (terminal of the block of terraced houses). This first factor is a gross index of the outer surface (i.e. the

[4] Energy performance index for envelope in winter conditions.

[5] Energy performance index for envelope in summer conditions.

[6] Energy performance index including envelope and plant system (global performance) in winter conditions.

surface dispersing heat to the outside), less for a row of buildings as they share with the adjacent buildings two walls (adiabatic, where there is heat exchange);

- dimensional characteristic: 1, 2 or 3 floors above ground (relating to buildings occupied/heated). Also in this case the data is index of greater or lesser gross external surface;
- technological feature: masonry exterior light, medium or dark colour (as indicated in UNI TS 11300-1:2008). The external colour of the building influences the thermal storage from solar radiation incident (the darker is the facing, the greater is the solar radiation that catalyses). The solar radiation is transformed into heat gain in winter and overheating in summer[7].

The data thus obtained were attributed to each building to be revised on the basis of the specific characteristics of each building. The database is decomposed with criteria weighted according to the individual value of transmittance and according to the real value of surface dispersion. This is crucial because some components of the external borders have more weight on the global dispersion of the housing: these include a vertical closure and especially the cover. The parts are then incremented, in the case of thermal bridges, or reduced, in case of presence of upper (roof) or lower (basement cellars or underground) buffer elements, and finally added together to obtain the $EP_{i,invol}$ and $EP_{e,invol}$ values representative of the individual building. The rated efficiency of buildings in different scenarios of regeneration was conducted in a similar way as described for the current situation[8].

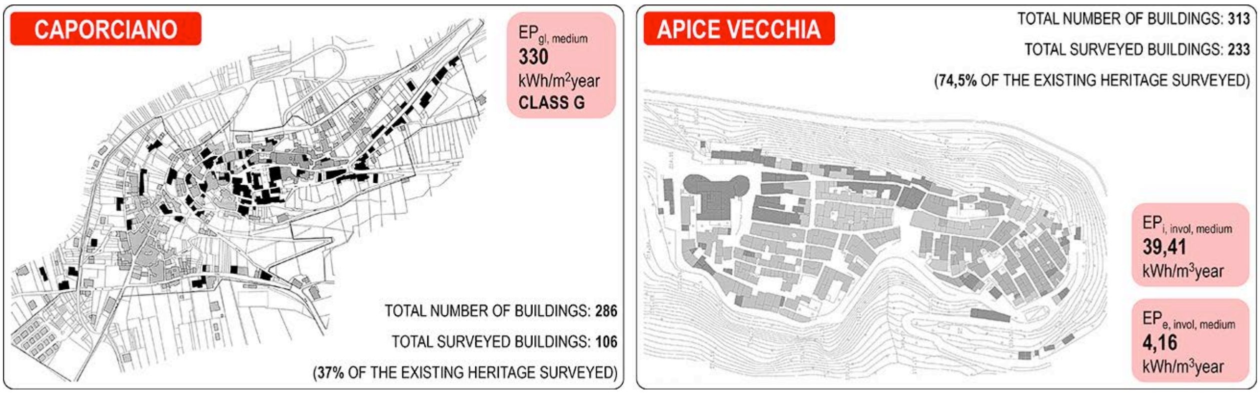

Figure 3. Calculation of the overall energy performance of the villages of Caporciano and Apice Vecchia.

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[7] The calculation of these contributions is relatively complex and even more difficult is its parameterization (different is the case of other technological specifications of the enclosure, such as the thermal transmittance, linked in a linear fashion to the dimensional data of the surface of which is characteristic), for this reason it was decided to include them in the calculation of the benchmark data, avoiding further complications in the application of the method of parametric energy assessment.

[8] For the case of Apice Vecchia was necessary to include the contribution of the plants, absent in the current situation and thus not included in the first evaluation.

4.3. Definition of a database and components analysis

The wide amount of information about Caporciano and Apice Vecchia architecture has been implemented within a database of construction technologies and materials most widely used in the two contexts. Each building element was evaluated in a preliminary way from the technological, thermal and hygrometric point of view in order to identify the residual potential and to advise retrofit guidelines, in particular:

- technological composition: description of subsequent envelopes material layers, with information about thickness and thermal conductivity;
- thermal evaluation: definition of the total thermal transmittance, thermal abatement and phase shift;
- hygrothermal evaluation: definition of critic months for superficial moisture and for interstice moisture (diagrams with temperature and pressure behaviour in January, March, June, September).

C.V.1 MURATURA A SACCO			
C.V.1.1_MURATURA A SACCO + INTONACO ESTERNO			
Strato		Sspessore (cm)	Conduttività (W/mK)
1	intonaco civile calce e gesso	2	0,7
2	pietra da taglio calcarea	25	1,4
3	riempimento di pietrame con malta di calce debole	10	2
4	pietra da taglio calcarea	25	1,4
5	intonaco esterno a base di calce idraulica	2	0,9
TOTALE SPESSORE		64	
VERIFICA TERMICA			
TRASMITTANZA TOTALE (W/m²K)		1,593	
ATTENUAZIONE		0,048	
SFASAMENTO (h)		17,11	
VERIFICA IGROMETRICA			
CONDENSA SUPERFICIALE		Mese critico: Gennaio fRSi Max: 0,653 fRSi: 0,694 NESSUNA CONDENSA	
CONDENSA INTERSTIZIALE		Non si verifica condensa interstiziale in nessun mese e nessuna interfaccia	

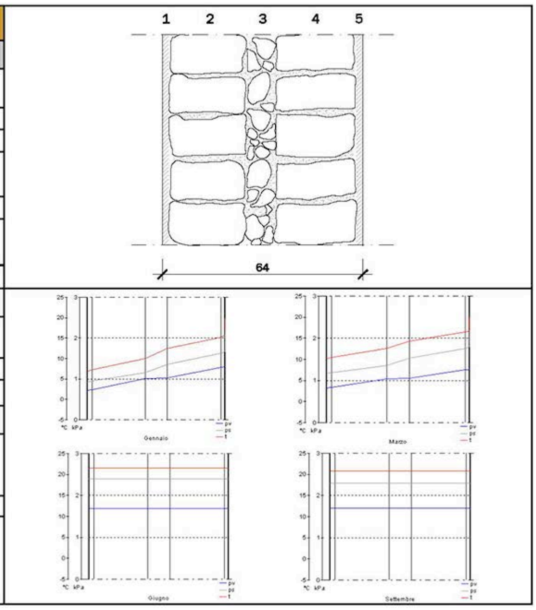

Figure 4. Example of a performance analysis[9] for the definition of a database concerning construction technologies and materials surveyed in the village of Apice

[9] Material's thermal properties have been defined from the indications of the current legislation on energy efficiency, which provides tables of the main building components and materials most commonly used. In particular the following standards: UNI 10351:1994 - *Building materials. Thermal conductivity and vapour permeability*, UNI EN ISO 6946:2008 - *Building components and building elements - Thermal resistance and thermal transmittance - Calculation method*, UNI EN ISO 10456:2008 - *Building materials and products - Hygrothermal properties -Tabulated design values and procedures for determining declared and design thermal values*, UNI 10355:1994 - *Walls and floors. Thermal resistance values and method of calculation*. It was considered appropriate to proceed with the simplification of the energy behaviour of closures in cases of complex technologies, stratigraphic sequences of non-homogeneous materials or in case of lack of references within the existing schedules in the abovementioned regulations.

Vecchia. For each type are indicated: the technological stratification of the material of the closure; the thickness and thermal conductivity; thermal analysis, showing the total thermal transmittance (W/m2K); the attenuation value (dimensionless) and thermal lag (h)[10]; the hygrometric check, indicating the critical month for the formation of surface condensation and graphs relating to condensation formation.

5. Definition of integrated intervention strategies for energy and environmental enhancement of historic buildings

By relating morphological, technology, energy and environmental data and information about protection of historical values and languages, it has been possible to develop different retrofit scenarios to be applied to each building, for an immediate comparison and support to the formulation of an intervention program in line with Public Administrations' priorities and needs.

The main objective of the proposed strategies is the integration of activities to increase envelopes' energy performance, structural interventions aimed at improving the seismic behaviour and adaptions of the plant system for conditioning in summer and winter, fed by renewable energy sources (produced on site or relocated nearby), in accordance with the typical building characteristics and historical value.

Given the colder weather conditions, the strategy adopted for Caporciano is primarily aimed at achieving high global winter performance (EP_{gl}) through the substantial thermal insulation of the building envelope ($EP_{i,invol}$). Some of the proposed solutions are:

- the strong increase/add of insulating material layers in roofs, external walls and lower floors;
- the reduction of thermal bridges due to material discontinuities;
- the improvement of walls insulation between adjacent units;
- the replacement of existing windows with new windows;
- the construction of "energy spots", small cogeneration plants for neighbourhood, fuelled by local wood biomass and placed (with static consolidation function) in some of the buildings in which the high degradation would make any functional recovery unrealistic.

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[10] The data analysis of energy and environmental performance of the materials that constitute the external borders of the buildings was carried out according to the calculation methodology described in UNI TS 11300-1:2008 - *Energy performance of buildings - Part 1: Evaluation of energy need for space heating and cooling*, paragraph 11 - *Parameters of Transmission Thermal - Thermal characterization of envelope components*.

THERMAL INSULATION OF BUILDINGS' ENVELOPES	
UPPER ENCLOSURES (ROOFS)	▪ Addition/integration of insulation layers for heat losses reduction. ▪ New definition of the upper old buffers (insulated false ceiling, with high compatibility with historic structures).
	Insulation material's features: - minimum thickness, in order to maintain external alignment and internal rooms' height; - vapor resistance.
VERTICAL ENCLOSURES (WALLS)	▪ Thermal performance enhancement of external walls toward the street and between units, through internal (if in presence of external decorations) or external (if in presence of surface correspondence) insulation layers. ▪ Thermal performance enhancement of walls between units through insulation in both wall's faces. ▪ Thermal bridges reduction through external insulating plasters.
	Insulation material's features: - for internal insulation of external walls: minimum thickness, vapour-resistance; - for external insulation of external walls: insulation plaster made by natural hydraulic binders and light organic insulating materials compliant with historic features and with wall's irregularities; - for internal insulation between units: high thermal mass in order to absorb heat made by the plant system.
LOWER ENCLOSURES (GROUND FLOORS)	▪ Addition/integration of insulation layers in ground floors in case of high shape factor (buildings with only 1 floor above ground). ▪ Insulation enhancement of floors between heated and non-heated spaces in case of high shape factor (buildings with only 1 floor above ground).
	Insulation material's features: - vapor resistance; - compression resistance; - non-hygroscopic.
EXTERNAL WINDOWS	▪ Existing windows replacement with high thermal value windows, preferably with wooden-frame.

Concerning Apice Vecchia, due to the warmer climate, a strategy aimed at achieving a higher performance for the building envelope in summer ($EP_{e,invol}$) was pursued, through the development of thermoregulatory function of the wall masses and the existing underground spaces for exploitation of fresh air reserves. However, even in the case of Apice Vecchia, the need of thermal insulation improvement in winter has made necessary to take actions in order to reduce heat flows through the addition of insulating material on each technical elements (always respecting historical and cultural features), with a strategy close with the one previously used for Caporciano, but acting in an integrated way with the summer needs. Some of the proposed solutions are:

- the strong increase/add of thermal mass, solar reflection and ventilation layer in roofs;
- the exploitation/increase of existing enclosures masses for enclosures toward the streets and for floors directly on the ground and between adjacent units;
- the replacement of existing windows with new windows with sun protection devices;
- the use of electric heat pumps in individual housing units coupled with low temperature radiant systems or mechanical controlled ventilation, powered by renewable energy produced by photovoltaic system located on the roof of some host-buildings (preferably owned by the Municipality).

THERMAL INSULATION OF BUILDINGS' ENVELOPES	
UPPER ENCLOSURES (ROOFS)	▪ Addition/integration of thermal mass in order to enhance phase-shift and attenuation potential of envelopes, strongly hit in the summer period. ▪ Enhancement of external solar reflection, in order to reduce heat accumulation. ▪ Addition/integration of a ventilation layer under roof claddings to increase dissipation.
	Insulation material's features: - minimum thickness, in order to maintain external alignment; - high thermal mass; - high solar reflection.
VERTICAL ENCLOSURES (WALLS)	▪ Exploitation of existing thermal masses in external walls toward the street, to reduce overheating in summer. ▪ Exploitation/integration of existing thermal masses in walls between units, to take away heat from the surroundings and improve thermal comfort.
LOWER ENCLOSURES (GROUND FLOORS)	▪ Exploitation/integration of thermal mass in ground floors, to reduce overheating in summer. ▪ High addition of thermal masses in floors between underground non-heated spaces and heated-spaces.
EXTERNAL WINDOWS	▪ Existing windows replacement with high thermal value windows, preferably with wooden-frame. ▪ Addition of external solar shading/protection devices in case of high windows exposure.

Even if a more specific orientation of the strategies was identified for each settlement, for both villages a hierarchy of intervention levels was provided, in order to ensure high compatibility with different historic levels, which impose different criteria of protection, and thus, performance virtuosity, i.e.:

- basic refurbishment: minimum energy enhancement actions and attention to historic and monumental features identification;

▪ “energy restoration”: environmental original buildings features implementation, with enhancement and recovery of the environmental and energetic self-control capability (“environmental metabolism”) of the building itself;
▪ energy retrofit: systemic energy retrofit action on more recent buildings with lower monumental and historic features.

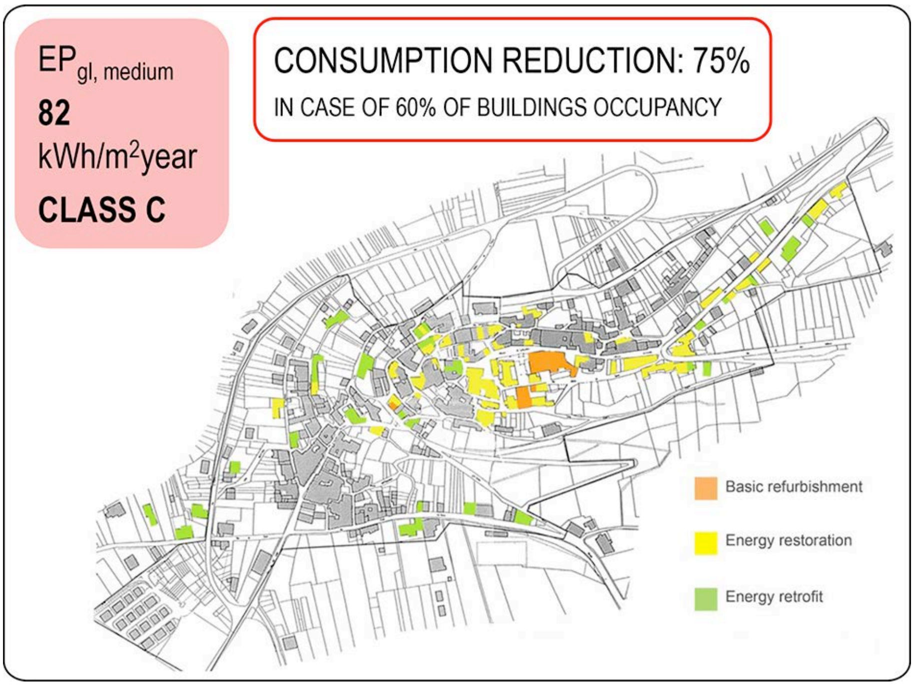

Figure 5. Different levels of performance reached for the different kind of building basing on the historic value and preserving need.

It is also possible to recognize a common denominator for the adopted strategies, i.e. the attention to local and regional peculiarities: in fact, any strategy must fit to the specific climatic, environmental (natural and anthropogenic), technological and cultural requirements and should not be a simple transposition of standardized practice, although effective, used in other contexts[11].

Thus, the adoption of alternative technologies must be strongly related to “short chain” resources, such as forests for wood products, the agricultural system for straw and breeding farm for sheep's wool (Forlani, 2011), can create a perspective of regeneration and/or conversion of the existing productive unskilled factories through a process that will encourage green economy as an engine for economic growth.

[11] Reference to the strategies of hyper-insulated passive house standard of northern Europe that comes strongly into crisis if applied, without appropriate modifications, in contexts characterized by a Mediterranean climate with complex summer-winter and day-night behaviours.

Material \ Performance	Inner side (wall)	Inner side (floor)	Outer side (wall)	Outer side (roof)	Outer side (floor)	Breathability	Tighness	Thermal performance	Performance improvment	Historic building compatibility	Local row promotion
Thermal plaster	●		●			●	●	●	●	●	
Sheep wool	●	●		●		●		●	●	●	●
Wood fiber	○	○	○	○		○		○○	○	○	○
Reflecting multilayer insulation	●		●	●			●●		●●		
Cellular glass	●	●		●	●		●	●	●		
Leca		●			●	●		●	●		

Figure 6. In both cases, the verification of performance improvement solutions provided by enclosures during the design phase was gathered in parallel with the evaluation of insulation materials, chosen in each case basing on performance targets and for an economic regeneration of local productions.

6. Plant integration: from the building scale to the urban one

Thanks to the architectural, technology and energy survey of the villages, it was also possible to define strategies for the integration plant systems for heating and air conditioning.

In the case of Caporciano, in which energy networks are currently present and functioning, some buildings, whose degradation would require substantial consolidation or a scenario of a demolition and reconstruction, have been identified. These buildings, renamed “energy spots”, were the subject of an innovative experiment aimed at conversion in CHP neighbourhood plants in which to place a small turbine that can generate heat and electricity by burning wood biomass from the pruning and maintenance of the surrounding forested and agricultural areas. Each building could therefore be served by a network of mini-district heating system that can make particularly efficient the entire village.

For Apice Vecchia, the geological soil features (presence of frequent large cavities in the ground that caused several crashes and made many unstable buildings in post-earthquake) oriented the research towards different proposals related to the integration of systems for summer and winter conditioning: electric heat pumps in individual units coupled to low temperature radiant systems or mechanical ventilation. These devices are powered by renewable energy sources whose production is spread in another place and electricity is then channelled into the local network, already set up and connected to Apice Vecchia. The energy will be produced by a photovoltaic system located on the roof of some host-buildings (preferably owned by the Municipality), so that it is not needed to subtract further ground surface.

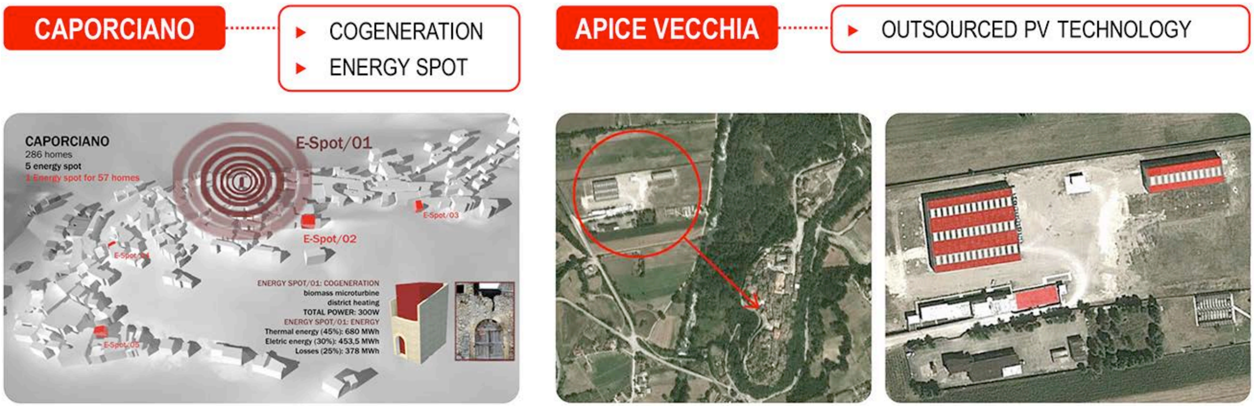

Figure 7. Different approaches for plants integration at urban and building scale in Caporciano and Apice Vecchia, using renewable sources.

7. Integration between energy and seismic aspects

To cite just a few solutions identified by the studies, where it is necessary to consolidate existing wooden floors (inter-storey or roofs) or the substitution of metal slabs or brick and masonry, it is considered advisable to use mainly wooden technologies, made integral to the perimeter walls. Technologies that, in addition to being historically compatible with the building, are particularly light, thereby reducing the weight on the vertical structures. Above the wood support structure, instead of a rigid concrete slab, it is possible to insert a double deck cross (or, better, a double layer of multilayer structural panels, if possible), which generates rigid elements in their plane. The boards must be connected to the perimeter walls (each about 40-60 cm) through metal plates (about 60 cm long), made of wood and screwed on the ground, and, if necessary, to get "collaborating slabs" with the beams, also made integral to the work frames system. The plates are then connected in a punctual and widespread way to the walls system by means of armed seams and perforations made with insertion of steel bars embedded with resin or special mortars and welded to the previous dishes[12]. Another operation that may be necessary to make vertical elevation structures firmly with the horizontal ones or with the flaps is to set up wooden ring beams (especially the coverage level), also connected to the wall in a diffuse way through reinforced perforations.

[12] These plates should also continue every 2-2.5 meters and reach up to the opposite wall to bind better to the whole with pulling effect (both in the case of the floors, both in the case of pitched roofs only, and finally also with shell double-pitched roofs connecting the wood floor to the wall plug or the ridge beam to make roof plans synchronous).

In the case of ring beams and "dry" slabs, the reduced stiffness of the wood and its best performance in reducing the linear thermal bridge induced, compared to jets of reinforced concrete, provide compliant solutions that accompany adequately the fragile historical walls while upgrading building's energy efficiency. Also the diffuse seams system (previously cited) of the slab on the walls, which in many cases can replace the ring beam if the wooden floors are placed further plates on the walls perimeter, is a minimally invasive solution and capable of limiting heat losses (only punctual thermal bridges).

8. Conclusions

Strategies suggested for Caporciano and Apice Vecchia and their intervention scenarios have been formulated to integrate energy and environmental enhancement with settlements' refurbishment and buildings' seismic improvement, which are essential to ensure a new life cycle in conditions of comfort and safety for villages. The most original result is the creation of a 'fast' analysis procedure and proposition of interventions, which takes properly into account buildings' historical memory and identity, operating on the compensation of the whole settlement's performance and not focusing only on the individual building. The attempt to transform the tragic event in new opportunities is mainly based on the natural predisposition to an effective intervention given by the earthquake's effects on buildings and to try to trigger a local chain of "production for reconstruction".

9. References

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