# Energy Efficiency in Historic Buildings, the case study of the National Theatre of Rhodes, Greece and of the Zena Castle, Italy

***Maria Kikira [a], Elena Gigliarelli [b]***

[a] Architect, Department of Buildings, Division of Energy Efficiency, Centre for Renewable Energy Sources and Saving-CRES, Greece and researcher, University College London Energy Institute, UK
[b] Architect, CNR - ITABC Institute of Technology Applied to Cultural Heritage, Italy

## Abstract

The potential of energy saving measures in historic buildings is of great interest, due to the increased building stock in European level, the particularities in their architectural form, typology and age of construction, the energy efficient initial design and their specific use and operation. Museums, theatres, churches, as well as offices, universities and hotels, are accommodated in historic buildings. Even if historic buildings are excluded from the Energy Performance of Buildings Directive 2002/91/EC, the need for revitalising and reducing energy consumption in such constructions is rather a challenge towards sustainability and $CO_2$ emissions cut.

The aim of this paper is to examine the potential of energy efficiency in historic buildings and communities, presenting the particularities, barriers and challenges in this context. Recent results from an ongoing European programme titled 'SECHURBA' are assessed, highlighting the work of seven countries, in relation to sustainability prospects of historic buildings and communities.

A study of an example of historic excellence such as the National Theatre of Rhodes in Greece and the Castle of Zena near Piacenza in Italy is presented. The energy audit and energy efficiency study reveal the quality of the design and construction of such buildings and underline the prospective of envelope and cooling system improvement, while revitalising their use and restoring their architectural characteristics.

*Keywords: cultural heritage, building envelope, energy audit, bioclimatic principles, saving potential*

## Introduction to Historic Buildings and Communities

European and national targets and measures towards energy efficiency and integration of renewable energy sources are firm with limited time tolerance. Sustainability and environmental awareness set as priorities into the construction industry, focusing on existing high consuming building stock. Historic buildings and communities urge to follow and even lead these initiatives, even if the challenges and barriers often predominate these goals. The establishment of a synergy between the cultural heritage protection and the sustainability observance consist the aim of the issues raised in this study.

Designing and retrofitting historic buildings requires a holistic approach, considering architectural, cultural, energy and economic viability. This approach differs from the traditional design/build process, as it's necessary to examine the integration and interrelation of all building components and systems and the merging of old and modern technologies.

The Directive on the Energy Performance of Buildings (Directive 2002/91/EC) [1] and its recast [2] introduce incentives and obligations for public and private sector to save energy and reduce running costs. However, historic buildings are excluded from these commitments as stated in the recast: *"Article 4 - Setting of energy performance requirements: Member States may decide not to set or apply the requirements reffered to in paragraph 1 for the following categories of buildings: buildings and monuments officially protected as part of a designated environment or because of their special architectural or historic merit, where compliance with the requirements would unacceptably alter their character or appearance;"* [2]. Apparently, this does not mean that historic buildings could consume energy beyond any threshold. The enrichment of knowledge and scientific research into the sustainability and energy efficiency of historic buildings is important, considering their vast potential all over Europe. Even so, the reuse and rehabilitation of a historic (or not) building consist an energy efficiency measure itself.

**SECHURBA linking European countries**

SECHURBA (Sustainable Energy Communities in Historic URban Areas) [3] is a European project funded by Intelligent Energy for Europe, with a consortium of 13 organisations from 7 EU member countries. It aims to study barriers and prospects of various historic urban communities and buildings with diversity in local and national cultural framework. A critical target is to develop Historic Community Climate Change Strategies and route maps for intervening in such culturally sensitive areas.

Initial findings from this project are presented in this paper, addressing common characteristics and also individualities of such case studies.

**Historic buildings characteristics**

The following characteristics of historic buildings could be indicatively addressed:

- Architectural and historical excellence.
- Significantly high heights / large volumes *(+) efficient cooling performance, (-) high heating demand.*
- Increased thermal mass, increased wall thickness, solid walls with no insulation *(+) control of internal temperatures, smooth temperature fluctuation, qualitative envelope performance.*
- Controlled and limited openings (window to wall ration often less than 20%)…while contemporary design move towards light and total transparency *(+) control sun and light (-) limit passive heating potential.*
- Recessed windows and openings *(+) Self-shading, moderate overheating.*
- External overhangs, patio, terraces, trees, internal courtyards, roof openings, solar and ventilation chimneys *(+) Surrounding space cooling and ventilation, improved microclimate.*
- Earth and light colours *(+) Environmental and climate deference.*
- Natural lighting and ventilation *(+) Human satisfaction and expectation success standards.*

**Fig. 1: Photos…thermal mass, colours, openings, dignity of historic buildings. (Source: [4])**

The above characteristics could be easily considered as bioclimatic: design and build according to the local climate. Therefore, historic buildings embody bioclimatic principles, and as soon as they are exploited efficiently and not vitiated through ages, revitalization and sustainability are realistically achievable.

However, “Having a listed building is like a curse!”, an owner of a historic building reported during a SECHURBA project workshop. The procedures of intervening in such buildings often constraint any willingness to conform the architectural and cultural heritage into the contemporary demands.
Energy efficiency building interventions have been widely developed by the research and market community, such as the reduction of energy demand and thermal losses through envelope and

installations improvement, the integration of renewable energy sources, the awareness rising of occupants, etc [4]. However, interventions in historic buildings -except of architectural preservation purposes- require a holistic study in order to address potential risks such as: moisture and condensation occurrence, chemical incompatibility of old with new construction materials, failures due to limited construction knowledge on restoration applications with sustainable technologies. In addition to that, various interventions in time that have been possessed to a building structure and have never been recorded or monitored, constrain a thorough picture of actual building elements.

**Historic Community, not just like the others**

Projecting this potential into perspective, historic communities –and especially in urban city centres – address several particularities and challenges such as:

- High number of visitors and seasonal population (peaks in services, infrastructure transportation, networks).
- Multi-cultural character, challenge to accommodate diversities and individualities.
- Limitations to integrate renewable energy sources.
- Past and future cohabitation, alternation or retention of character and cultural profile.
- Development versus functionality – often pedestrianisation implemented in a historic centre cause problems of accessing to services and shops within this area.
- Residents versus visitors, trends of changing uses from residential to commercial.
- High cost of living, increased value in historic urban areas.
- High tourism attraction (potential for demonstration and awareness activities and projects).

For example, a community case study in Athens city centre sized 46ha, has a number of 260 listed buildings and a conservation area of 4ha. However, it is recorded that most of the buildings are deserted due to the poor legislative and financial incentives and to the high tourism density and immigrant population. Therefore, except of sustainability viability, the social, economic and security priorities are high in the agenda of the municipal area reformation plan.

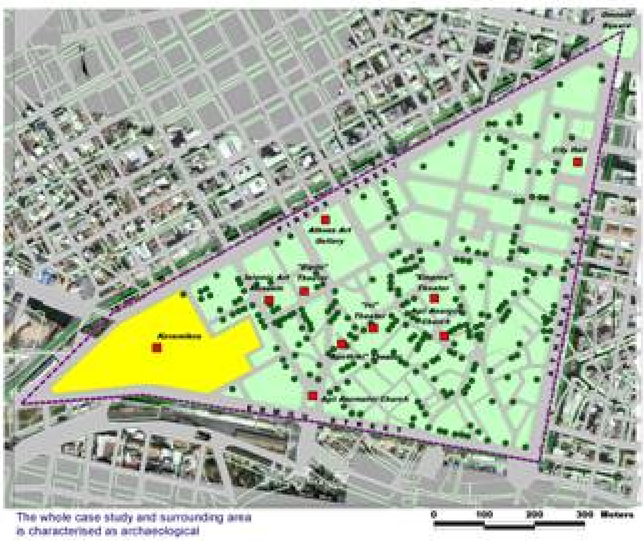



**Fig. 2: Athens case study area showing listed buildings (green spots) and conservation area (yellow area). (Source: [3])**

How could historic communities contribute to sustainability and environmental protection? An integrated approach need to be followed through targeted interventions in: Environment, Society, Culture and Economy. The key role is the local authority and society awareness, as well as their participation and commitment.

## NATIONAL THEATRE OF RHODES, GREECE

### Introduction to the history

National Theatre of Rhodes (NTR) was designed by the architect Armando Bernabiti and built during Italian possession in 1930's. It was used as a lyrical theatre; it has a rectangular layout and could be characterized as a "double shell" construction with the auxiliary spaces in the perimeter, working as buffer zones between the stage and the surrounding areas. The building was subjected to serious interventions during the period 1972-77 when air conditioning system was installed, altering few architectural and bioclimatic building elements, such as sealing of openings and demolition of certain internal partitions (for the mechanical system). However, these interventions were limited to the internal of the building and did not extend to the external appearance and form.

**Fig. 3: External images of the building – Left: East façade, main entrance – Right: South facade. (Source: Division of Preservation of the Medieval City of the Municipality of Rhodes)**

NTR could be considered as a building monument to the island due to its historical significance, to its location within the city and its size, fact that increases (or constraints) the challenge and the prospective for future revitalisation interventions, as being out for operation since 2004. Thus, the Municipality of Rhodes, division of Preservation of the Medieval City of Rhodes undertook the initiative to re-operate this building, having a holistic approach towards the refurbishment process by adding the value of integrating energy performance principles. In cooperation with CRES, an energy study has been developed [6] in order to assess the building's energy performance and bioclimatic elements, evaluate certain energy efficiency measures and examine the possibility of PV integration.

The proposed energy saving interventions were mostly based on the findings from the energy audit and the thermal simulation parametrical analysis, integrating contemporary and new technologies and decreasing the building's operation cost (for heating, cooling and lighting).

### Existing condition

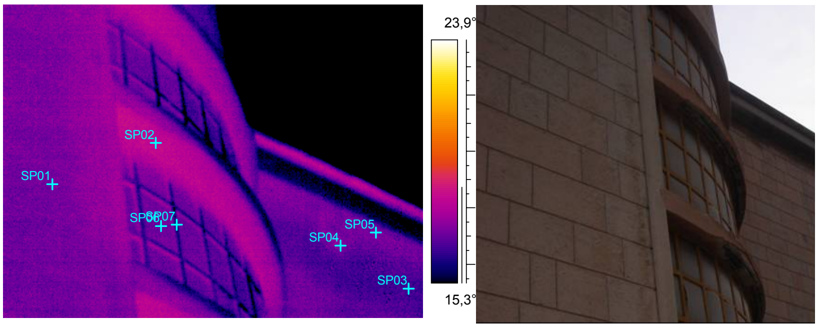
The building structure has high thermal mass of 35 – 45cm reinforced concrete and of 27,5cm brick walls, with 4,5cm external coating of imitating stone surface and plaster coating in the internal part of the walls. The form and shape of the windows and frames define a historic building's appearance with recessed windows to 40-60-95cm (except of the curved transparent surfaces) which result to a summer shading of 60-100%. The limited proportion of window to wall ratio stands as in most historic buildings with 7% in west, 14% east, 16% north and 20% in south building façade. Windows are single glazing with wooden frames, while the curved surfaces are alabaster with wooden frames. Certain openings in vertical surfaces and roof have been sealed during 1970's interventions, limiting the natural lighting and ventilation dynamic. Large heights and volumes are recorded in most spaces, increasing the demand for heating and decreasing the demand for cooling. A characteristic of the building is the "double envelope" layout as the main stage forms the core of the building, surrounded by secondary and auxiliary spaces (greenrooms, circulation areas, offices, exhibition areas, etc).

**Energy Audit findings**

From the thermographic analysis of the building the following findings could be summarized [7]:

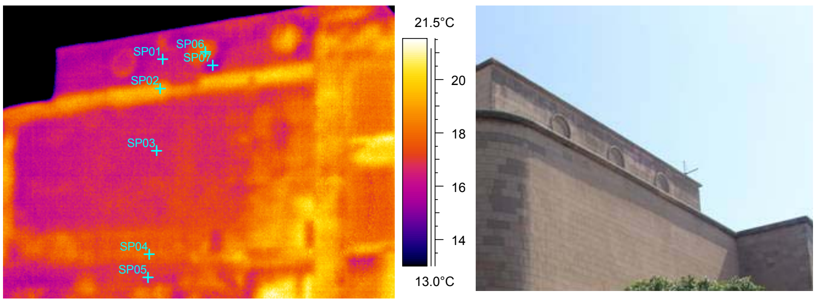
- The construction elements of the building envelope have few damages from the plaster collapse and high humidity concentration in the walls, especially in the higher levels of the building.
- Moisture and condensation problems have been identified causing thermal bridging effect and further damage to the construction elements.
- High thermal losses through the openings are evident, especially from the single glass surfaces.
- Short run interventions in the structure of the building are needed in order to avoid corrosion of the reinforcement elements.
- The quality of overall construction is very high with minimum thermal bridging effect, despite its age.

Thermographic analysis is presented below for the three main building façades.



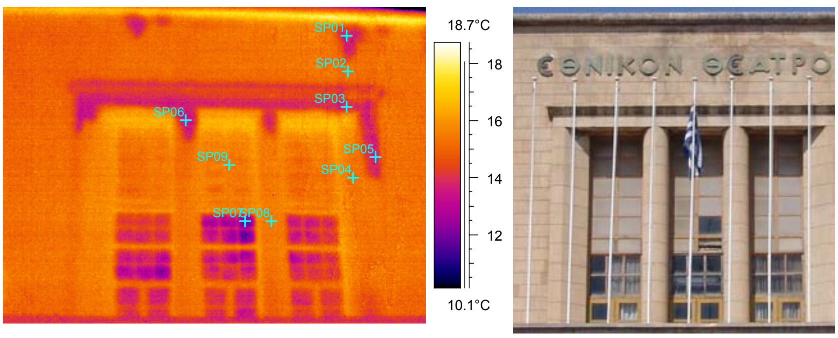

| Spot | Temperature |
|---|---|
| SP01 | 17,0°C |
| SP02 | 18,7°C |
| SP03 | 16,6°C |
| SP04 | 17,2°C |
| SP05 | 17,5°C |
| SP06 | 16,4°C |
| SP07 | 17,6°C |

**Fig. 4: Thermographic analysis of alabaster surfaces – north façade. (Source: [6,7])**




| Spot | Temperature |
|---|---|
| SP01 | 16,5°C |
| SP02 | 19,4°C |
| SP03 | 16,8°C |
| SP04 | 17,5°C |
| SP05 | 16,6°C |
| SP06 | 18,0°C |
| SP07 | 15,2°C |

**Fig. 5: Thermographic analysis of top level – south façade. (Source: [6,7])**




| Spot | Temperature |
|---|---|
| SP01 | 13,8°C |
| SP02 | 15,6°C |
| SP03 | 14,0°C |
| SP04 | 15,7°C |
| SP05 | 13,8°C |
| SP06 | 13,6°C |
| SP07 | 11,6°C |
| SP08 | 15,5°C |
| SP09 | 15,2°C |

**Fig. 6: Thermographic analysis of east façade above main entrance – single glazed openings. (Source: [6,7])**

**Envelope Thermal Performance and analysis**

An extended simulation study followed the thermographic analysis in order to assess the impact of building envelope improvement as well as of the re-operation of natural ventilation.

Different scenarios have been studied in order to identify the potential energy saving from: the improvement of the envelope performance through insulation and windows replacement and from the restoration and re-operation of the horizontal and vertical openings for natural night ventilation purposes. It is apparent that the openings operate strategically for the natural ventilation and the decrease of the cooling demand, as they facilitate the warm air exhaust from the higher levels of the building (Fig. 7).

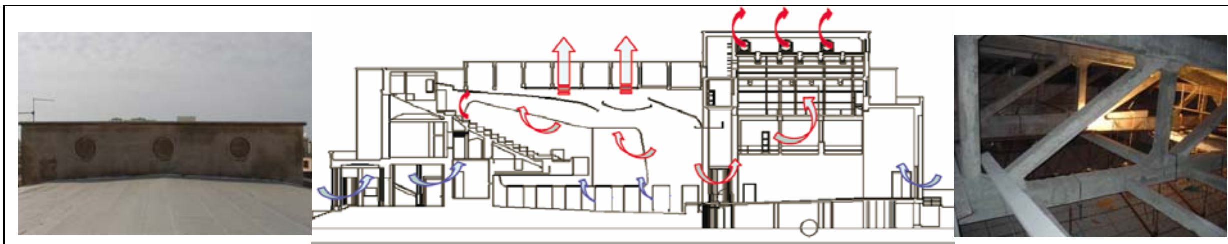


**Fig. 7: Air circulation through vertical and horizontal openings. Left picture: sealed skylights from interventions in 1970s, Right picture: sealed ceiling openings after interventions (Source: [6])**

The building was separated in 26 thermal zones according to their profile and use. The stage represents the largest volume followed by the orchestra area, the commuting spaces and the greenrooms. TRNSYS simulation software was used for the analysis with set point temperatures to 26°C for cooling and 20°C for heating.

Regarding the existing performance of the building, the study resulted to 31,58kWh/m$^2$ yearly demand for heating and 32,93kWh/m$^2$ for cooling. Examining the scenario that the building does not operate during July and August, the cooling demand decreases to 11,52kWh/m$^2$. The condition of the building is considered as poor, however the overall energy performance is satisfactory due to the 'double shell' construction, the envelope quality, the positioning of the openings and in general the bioclimatic design of the building. The analytical findings from the energy analysis are the following.

| **Proposed Intervention**<br>*Examined for 12-month use* | **Energy saving** | **Heating demand** | **Cooling demand** |
|---|---|---|---|
| Insulation placement to the external walls (internal) and roof (external) | 39,41 % | 21,55 kWh/m$^2$ | 17,54 kWh/m$^2$ |
| Replacement of windows from single to double glazing and improved frames | 2,95% | | |
| Replacement of windows from single to improved double glazing and frames | 4,29% | | |
| Insulation placement and replacement of windows with improved double glazing | 45,98% | | |
| As above, adding natural ventilation for the heating period, re-operating the vertical and horizontal openings *(from 23:00 to 6:00)* | 49,43% | 18,17kWh/m$^2$ | 14,45kWh/m$^2$ |

**Table 1: Energy saving potential of different improvement scenaria (Source: [6,7])**

The placement of the insulation internally or externally does not affect significantly the thermal inertia of the building, mainly due to the high quality construction and thermal capacity of the internal walls (especially perimetric of the stage). For the retention of the internal dimensions of the spaces (perimeter spaces are rather shallow) and due to the fact that external finishing would be replaced during the refurbishment process, external insulation has been decided in cooperation with Division of Preservation of the Medieval City, retaining the aesthetics and architecture of the building.

The graph below summarizes the results in energy demand for heating and cooling before and after the proposed interventions. It is evident that most significant impact to the building's energy performance is recorded in the peak winter and summer months due to the insulation addition and the natural ventilation techniques respectively.

The replacement of the windows might have a limited impact for the building overall (due to the limited percentage of such surfaces) however for the thermal zones in the perimeter of the façade, the impact is significantly higher.

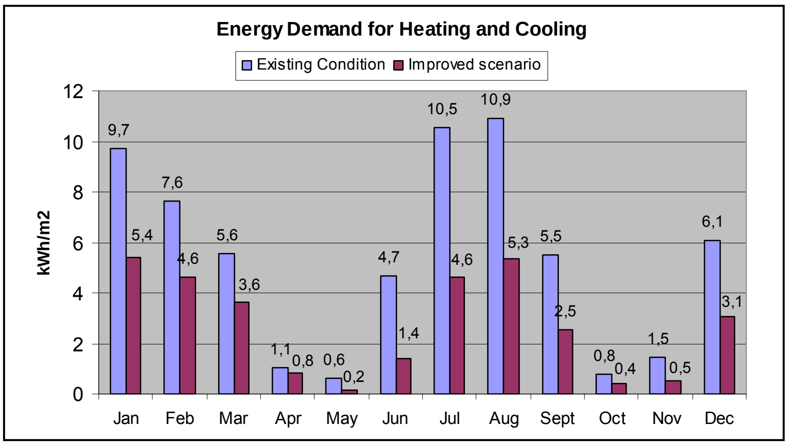



**Fig. 8: Building total energy demand for heating and cooling before and after the proposed interventions (Source: [6])**

The energy study included a day lighting analysis which is not explored in this paper, as well as other proposed intervention in the building electromechanical and management systems.

**Integration of Photovoltaic Panels**

The possibility to integrate photovoltaic panels in the roof of the building was also studied. Being a historic building, special attention was allocated to the positioning of the panels for architectural and aesthetic purposes. The option of roof mounted, following the roof inclination (3-5$^{o}$), facing south and placed 10cm away from the final roof surface for ventilation purposes, was decided. Based on available area, economic viability and historical preservation aesthetics, a system of 100m$^2$ was proposed, with a capacity of 13,6 kWp and estimated yearly energy production of 18 MWh. Special attention need to be ensured during the placement of the panels so as not to damage the roof structure and insulation layer.

For demonstration and education purposes to the public and visitors, an online screen system would present real time PV energy production data within a designated area inside the theatre spaces.

## CASTLE OF ZENA, ITALY

Another case study is the restoration project of Zena castle, for a functional recovery of this monument as a congress and business centre. The aim is to respect the integrity and authenticity of the monument, as well as its sustainability, comfort and 'livability' with the use of technological solutions for energy saving and renewable energy systems.

A research study has been progressed in SECHURBA project with the objective to explore the links between utilization and conservation in monuments and to develop evaluation models for energy adaptation in historical buildings. Thus, a multi-criteria analysis decision making tool is under development and it aims to assist the feasibility and compatibility process of new applying energy saving systems, as well as of alternative energy sources in ancient buildings and historical centers.

**Multi-Criteria Analysis (MCA)**

The Tool has been developed in order to evaluate the potential for Renewable Energy Source (RES) and Rational Use of Energy (RUE) integration at two levels: first evaluating energy saving options against physical characteristics, secondly a Multi-Criteria Analysis (MCA) to address aesthetic and historic features, energy saving systems, financial and administrative frameworks. Environmental and technical indicators have been introduced, together with economic and sustainability benchmarks. The concept of the design tool is presented in the figure below.

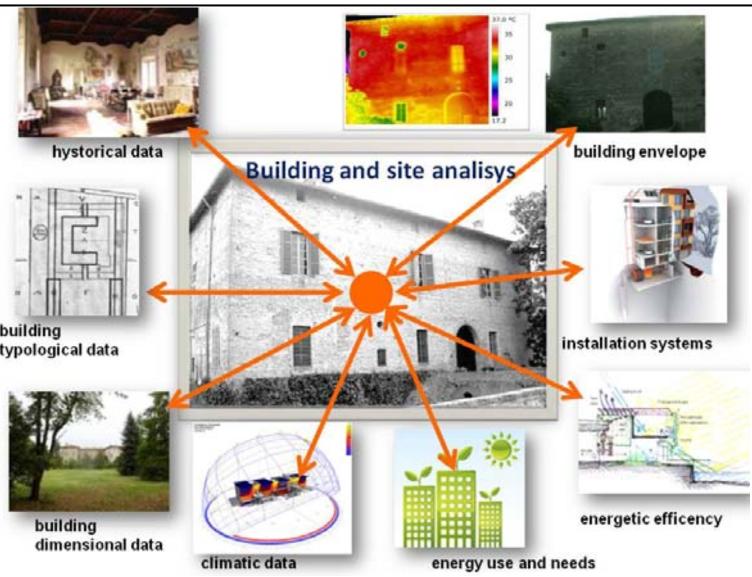



**Fig. 9: The analytic phase of the Multicriteria Analysis technique, a decision model that helps to identify different solutions for energy rehabilitation of historical buildings.**

Multicriteria approach was tested at Zena Castle SECHURBA case study, a medieval fortification located in alluvial plains of the Po river, which turned into a country residence in the mid 1700s. The aim was to choose the most sustainable solutions in such example of historic excellence.

**Energy assessment findings**

An energy assessment antedated the tool application, in terms of restoring its architectural characteristics, improving its construction and revitalizing its use and operation. Before proceeding with the sustainable energy review, an integrated preliminary survey on the historical, physical and architectural profile regarding the monument has been completed. The study was carried out by ITABC with an interdisciplinary, holistic approach for sustainable restoration. An energy assessment was done as well as an infrared thermographic analysis, which reveals thermal irregularities on the building envelope.

The design team involved into the technological upgrade of the castle aimed to combine high tech elements in the pre-existing installations. Emphasis was given to the innovative aspects of energy production and use of renewable sources, establishing also a low cost efficient energy solution.

The proposed interventions for technological and energy efficiency improvement mainly consists of:

1. Increasing the sealing and insulation of the building envelope (exterior walls, roofs and ground floors, shutters, doors and windows), therefore reducing the heating requirements.
2. Reusing some of the attic areas that meet the necessary sanitary and hygienic requirements for occupancy as living quarters, for optimum recovery of space.
3. Restoring accessibility, functionality and structural reinforcement to the eastern wing that was abandoned after the collapse of the intermediate floors (Fig. 10).

4. Recovery of the basement areas from both conservation and functional standpoint.
5. Design of an innovative energy production system for the entire architectural complex, supported by the use of renewable sources. Additionally, reduce energy consumption for cooling during the summer and heating during the winter and improve the hot water system and lighting of the indoor and outdoor areas.

The possible solutions for thermal insulation of the perimeter walls are only on the interior side, since the exterior envelope is constructed with fine mortar and visible brick, and there is no cavity in the walls. The ample thickness of the walls nevertheless provides an adequate thermal conductivity (U value). The interior insulation was adopted in two historic “service” areas of the castle which are therefore free of any frescoes, wall decorations or fine flooring. In these areas, a ventilation space with recycled plastic cement casings will be created for the ground floors, and the walls will be internally insulated with wool and wooden fibre panels covered with mortar. Within these areas, the design of a radiant heat and air conditioning system powered by a geothermal pump is proposed, using the groundwater from the several existing wells on the property. The precarious condition of the load bearing trusses and the roof covering require the disassembly of the roof, allowing the creation of an insulated and ventilated space for maximum comfort and durability of the structure (Fig 11).

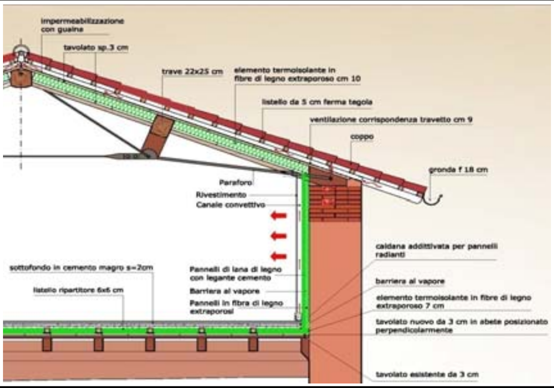



**Fig. 10 (left): The 3D model created for the functional and energy restoration of the eastern wing of the castle.**
**Fig. 11 (right): Solution adopted for the thermal insulation of the roof.**

In order to reduce high thermal losses from the envelope, insulation and sealing of the existing doors and window frames is proposed, by replacing the windows with triple-layer low-E glass (with Argon gas between the layers). In regards to the systems integration, several options were analyzed and a trigeneration system was selected, which allows autonomous production of electric power and water to water heat pumps by using groundwater.

## CONCLUSIONS AND FURTHER RESEARCH

Historic buildings and communities potential and challenges in terms of energy efficiency and renewable energy sources integration is indisputably interesting and valuable to the sustainability as well to cultural heritage protection and revitalization. The scope is to identify such interventions that preserve cultural heritage, enhance aesthetical and architectural potential, and ensure functionality, energy efficiency and high thermal performance. SECHURBA project and the above described case studies aspire to consist an exemplar example of revitalizing historic communities and buildings though an holistic and scientific approach. In the case of National Theatre of Rhodes, the energy study revealed a high potential of energy saving for heating and cooling load, decreasing energy demand almost to the half. Therefore, preserving the initial architectural excellence, detracting all later arbitrarily interventions throughout the time and introducing an integrated approach to energy restoration is an important asset.

Further studies need to be done in order to identify such parameters that will encourage European and national legislations to include and motivate these target groups into sustainability and high standard environmental performance. There is a need for targeted demonstration projects -and not only scattered case studies across Europe-, legislation initiatives, policy making and local authorities motivation, systematic research, monitoring and educational projects, increased competitiveness among historic and other communities and knowledge exchange and enrichment. Buildings need to revitalise within their lifetime, to provide high standard indoor environmental conditions, to consume less energy and operate for less…Respectively, historic communities need to efficiently exploit their energy, economic and cultural prospects through a balance of undergoing development. "..*Although people value the historic environment, this does not represent resistance to change*.." [8].

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