Energy-Related Innovative Concepts, Methods and Techniques for Sustainable Protection and Conservation of Historic Buildings in Urban Areas

The present paper is dedicated to a new integrated approach for the conservation of historic buildings and the application of sustainable technologies for Diagnostics, in order to increase the buildings' lifetime and the maintenance of their performance characteristics. The research activities have incorporated monitoring, NDT techniques and intervention works aimed at improving the energy efficiency of historical buildings

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Introduction

Italy has a large historic building heritage consisting of a) monumental complexes, protected by specific laws, b) immovables serving the main assets, as common historical buildings with or without characteristics of artistic value, but still having historic/artistic authenticity, and c) certain assets of landscape value, as they could be, for example, the historical centres.

This historic building heritage, mostly still in use, requires improvements in terms of energy efficiency and design interventions, in order to appropriately meet the increasing demands of users concerning hygrometric and moisture comfort, acoustic comfort and energy efficiency. In addition, the on-going global economic and social competition requires a number of operations essential to ensure that those historic buildings remain alive and also attractive for the housing market. Then the use of historic buildings and monuments under the best conditions of comfort and security is not merely a legal obligation but an essential part of the enhancement of this heritage and its protection.

Often do historic buildings and monuments remain "off limits" regarding energy efficiency; their restoration, very attentive to historic and aesthetic instances, completely excludes aspects involving

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sustainable energy. It would be advantageous that the rules on energy efficiency and those on protection and conservation are closely co-ordinated in order to address the problem of energy optimization in historic buildings, otherwise their management in terms of cost and consumptions is unsustainable and with no guarantee for their protection, conservation and use.
In this context, research and decision-makers have to make an effort to overcome the gap between scientific resources and real applications: this effort must reformulate the role of technologies in the field of cultural heritage, respecting the fruition of historic buildings and monuments and their conservation.
In this line ENEA provides its wealth of expertise developed during the years in the field of energy, environment and new technologies in order to address the problems of conservation and use of this heritage with a systemic approach that, starting from the structural and material recovery, ends in the resolution of issues related to energy efficiency and plants.

The Project: Methodology, Objectives and Strategies

On the above premises, we introduce a new integrated approach for the conservation of heritage buildings, the application of sustainable technologies for Diagnostics and some intervention works, in accordance with the results of the interventions, studies, and technologies, finalised at the realisation of low energy standards in historic buildings. This article refers to the results of thermal scanning and other Non Destructive Techniques of some historic buildings of Serravalle's historic centre (fig.1) in Vittorio Veneto, a small city, situated in Veneto, at around 40 km from Venice. This Diagnostic analysis belongs to the project called "Contratti di Quartiere II". The project is developed by an Italian partnership. ENEA is the scientific partner of the project and has involved the VTT Technical Research Centre of Finland in the same tasks. Within the project, ENEA has developed a methodology based on a systemic and integrated approach which takes into consideration the particular monumental character of the historic buildings (protected by conservation laws), the current needs of their users and, last but not least, the optimization of the energy performance of buildings in compliance with the recent European directives.

FIGURE 1 Serravalle historic centre, City of Vittorio Veneto, Treviso
Source: Ufficio Tecnico del Comune di Vittorio Veneto

The project started on 2006 and currently more than 80% of the scheduled works have already been carried out. The works involved a surface of 90.000 m^2 and an amount of 25 million euro invested mainly by the Italian Ministry of Infrastructures, with the support of regional and some private funds.
Some of the buildings involved, constructed between the XIII and XVIII centuries,. were of residential use, some of them empty, partly deteriorated and not in use. The overall objective renovation program is to find a new use, mainly public, for the buildings and innovative energy efficiency solutions to improve their comfort and performance levels in an acceptable contemporary stage. Before the renovation works, a large series of studies were accomplished, concerning the identification, measurement and documentation of technical performance parameters of the historic buildings, and also the quality of the indoor environment conditions. In fact, a correct intervention on a historic structure should begin from an accurate diagnosis of the building in order to minimize the interferences of the intervention with the historicity of the architectural structures, through a good knowledge on the existing materials and techniques of construction. The intention

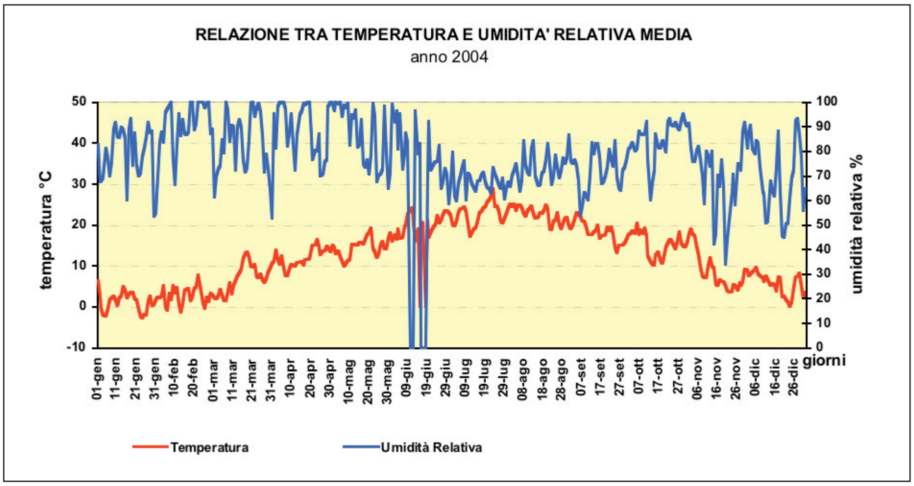

FIGURE 2 Thermo-hydrometric diagram elaborated on the basis of the collected data with relative relationship between temperature and relative average damp
Source: ENEA elaborations

of the project was to improve and conform the energy performance and the indoor conditions of the buildings involved and to assure the protection and sustainable conservation of their historicity, through the application of new technologies –such as non-destructive testing techniques, systems and innovative materials– and with the introduction of automation /smart systems for the building management.

Applications of Non-Destructive Testing Techniques in the Diagnostic Investigation of Historic Buildings

The analysis and diagnostic evaluations of historic structures have been executed with the application of Non Destructive Testing Techniques and monitoring during ante, intra and post operam. Some typical and difficult problems have been solved by the combination and the complementary use of different investigation techniques, such as endoscopy and videoscopy, IR thermography, Ground Penetrating Radar, ultrasonic testing, specific physico-chemical, and mineralogical petrography investigation. The NDT techniques can be very useful in finding hidden features, the presence of structural defects and the signs of damage detected on the building, but most of the NDT can give only qualitative results.
In addition, micro- and macro-climatic monitoring have been carried out for a long period, beginning from November 2007. These environmental investigations have allowed to determine the climatic profile of the historical centre of Serravalle (Fig. 2) and to process the main bearing elements for the buildings' recovery plan (Fig. 3), in compliance with the recent European Directive on the buildings performance. These environmental investigations and the results obtained have been used as input parameters for the creation of numerical models. NDTs have been applied in strategic points of the structure, previously identified, in order to know details on the geometry of the architecture and to solve the most difficult problems of hidden situations.
The building called *Palazzo Ex Monte dei Pegni* is the result of the transformation of more ancient buildings from the XII century, whose modifications have also involved the space of the main public square. The knowledge of the historical evolution of the building architecture is important to explain some evident signs of damage on the structures. The complementary use of different techniques on this historic building, as Ground Penetrating Radar (GPR) and sonic-ultrasonic tests, has allowed to verify its historical evolution and to accredit the hypotheses made on the basis of direct observations and bibliographical/archives information.
The historic evolution of the building is connected to the transformations suffered by the surrounding space

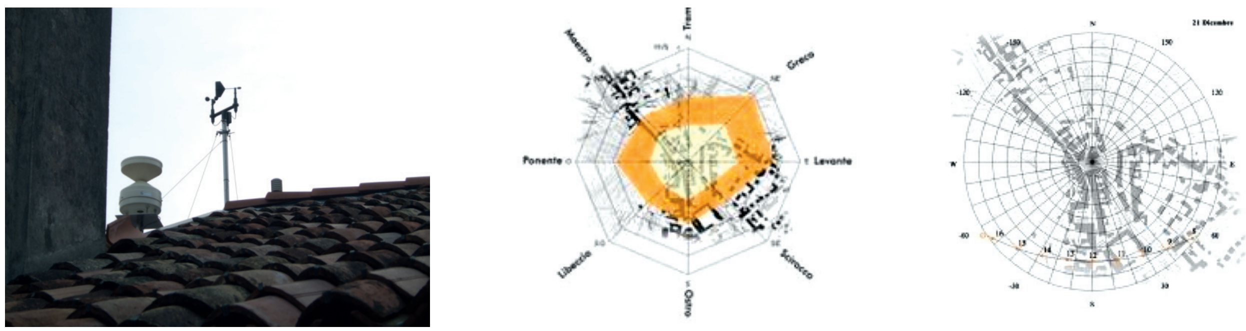

FIGURE 3 Prevailing winds and sun path diagrams on December 21st
Source: ENEA elaborations on ARPA Veneto and CRA-CMA climatic data

of the main square, in fact the columns of the porch are currently included in the masonry (Fig. 4).
Ground Penetrating Radar (GPR) investigations have permitted to find deep defects and hidden inclusions. This technique has consented to recognize the wall morphology and the presence of local defects, and has given information on the moisture presence within the floor and masonry. GPR technique uses a transmitting antenna to send a pulsed signal into the ground or into a wall or floor and an antenna to receive the echoes reflected by interfaces. The transmitted wave hits objects with different electromagnetic properties and the reflected signal is received by a radar antenna. The recorded information is reflected on a computer display. Suitable processing was used to reveal the presence of the hidden structures and to characterize their morphological properties. GPR provides a radargram, that is the image of the echoes reflected by the embedded scattering object. (Fig. 5)
Sonic and ultrasonic tests were used to detect the inside density of the material and cracks, and to control the masonry characteristics and the effects of the previous interventions (Fig. 6)
NDT testing, in particular IR Thermography carried out on the principal façade of *Palazzo Todesco* (XIII-XVII centuries) permitted to verify the state of damage to surfaces, the thermal bridges of the structures and material decay. The set-up of IR technique for the detection of a particular defect (discontinuities under the surface, hidden structures, moisture growth,

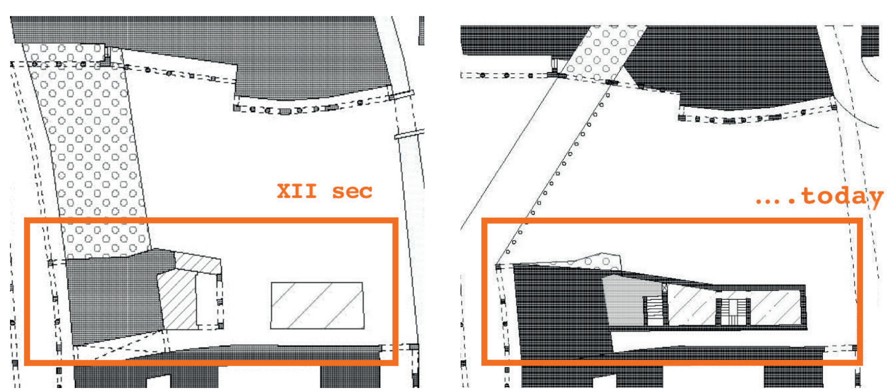

FIGURE 4 Palazzo Ex Monte dei Pegni: phases of historic evolution
Source: ENEA elaborations

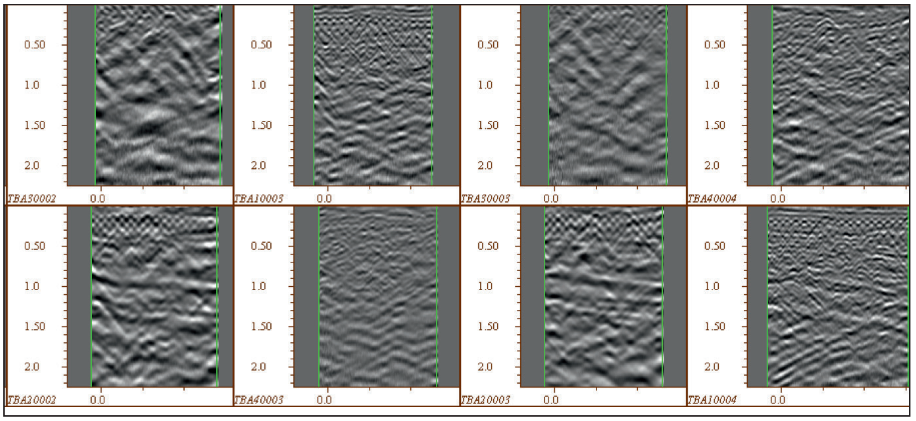

FIGURE 5 Processing of the radargrams at different depths
Source: ENEA elaborations

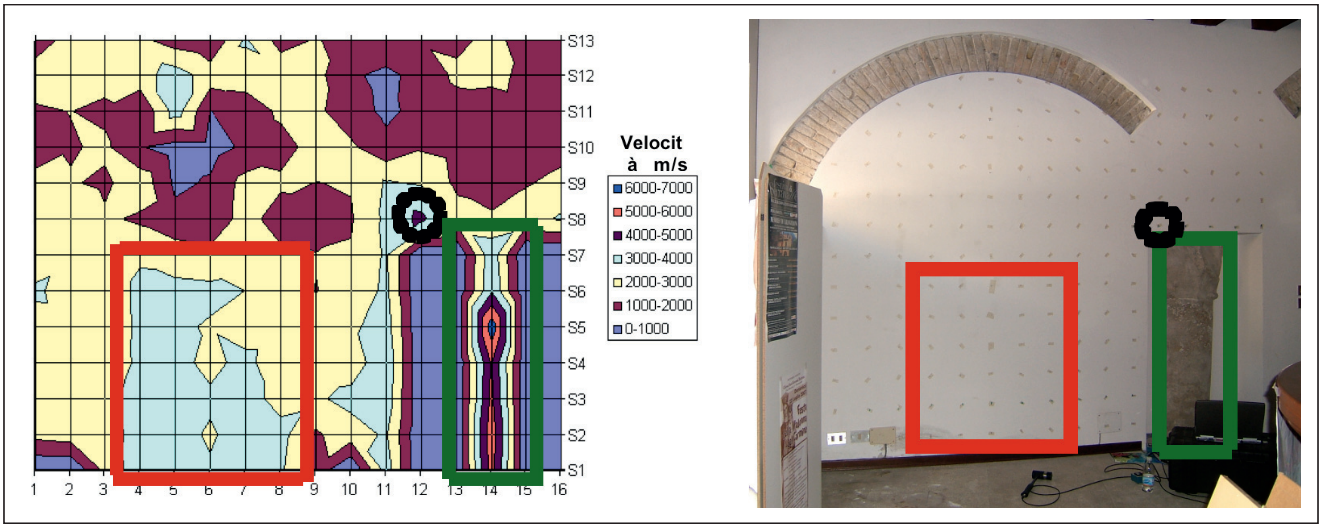

FIGURE 6 Distribution of the pulse sonic velocity on the wall
Source: ENEA elaborations

detachment from a wall) in an ancient structure needs a specific IR calibration. The IR Thermography allowed to create maps (thermograms) of the macroscopic defect distribution on the principal façade on the Flaminio square. This thermograms map has been compared to that of macroscopic damage on the south side.

In the building called *Palazzo Todesco*, sonic tests were carried out on the columns of the external porch on the west side. These tests have permitted to verify the structural damage to every single architectural element and the material homogeneity (internal crack, absence of material), and so to calculate the elastic 'modulo' and the mechanical resistance of the structures. The knowledge of the health conditions of the historical *Palazzo Todesco* has been essential for the preservation of its historical identity. In fact, these non-invasive techniques were applied to identify the structural integrity of the building (Figs. 7 and 8).

In the *post operam* phase, NDTs have permitted to verify and control the project standards previously characterized, and the energy efficiency of the buildings. In particular, the thermal scanning method

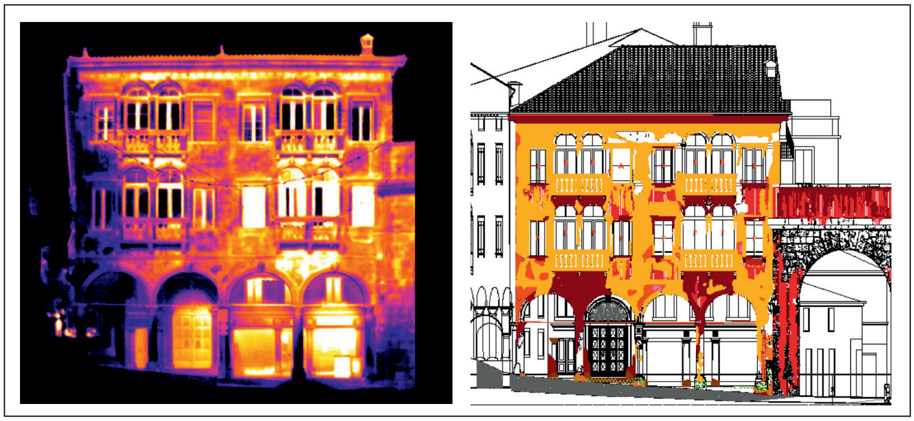

FIGURE 7 Thermovision applied to the principal façade of Palazzo Todesco and relative mapping of damage
Source: ENEA elaborations

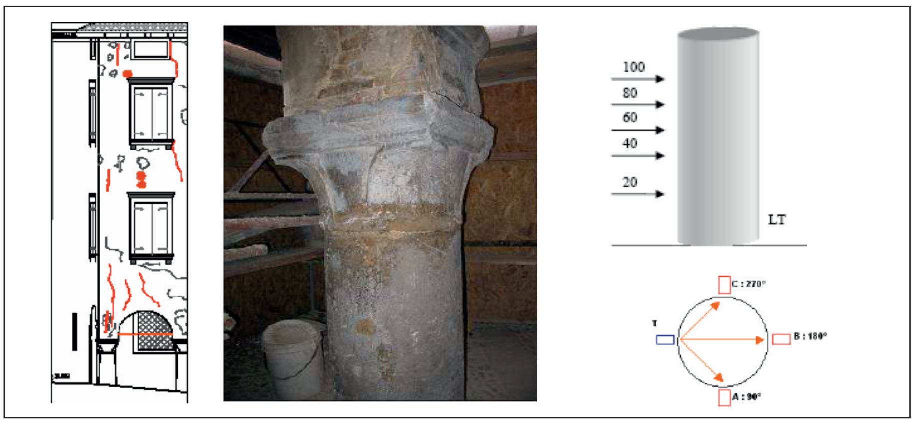

FIGURE 8 Palazzo Todesco. Crack pattern survey of the external west side and distribution of the pulse sonic velocity at a column of the porch
Source: ENEA elaborations

is finalized to study historic structures and their state of the art. IR Thermography is an effective NDT method for the evaluation of the indoor thermal-hygrometric conditions and the materials decay (with some limitations); it is used for the assessment of various traditional–historical materials and structures after they have been restored or repaired using different treatments. Thermography is a contactless and non-destructive investigation technique suitable for acquiring significant information about hidden structures and for long-term monitoring. As concerns historic structures, it allows investigating details of construction, damage and material decay, and interventions.

Thermography was one tool in the non-destructive testing toolbox, which was used to research on the condition and performance of exterior walls. Within thermography, also other indoor environment measurements were made by imaging with a thermal camera: CO_2, RH (relative humidity) and temperature measurements (air temperature and air speed), fundamental environment parameters. The distribution of the surface temperature is of course very important, but the correct approach is to measure the boundary air conditions, at the same time.

Thermal scanning of the building envelope and of other structures was made in the winter 2008. Two buildings were scanned outdoor and indoor with supporting indoor air condition measurements (*Palazzo Monte Dei Pegni and Palazzo Piazzoni*). Two buildings were scanned only outdoor (*Palazzo Todesco and Palazzo Ex Carceri*). The outdoor conditions were relatively good compared with the prevailing weather, because the temperature differences during the scanning varied between 15-20 °C and the weather conditions had been relatively stable 2-3 days before the measurements. Sun radiation impeded the scanning, so some façades could not be measured. The results were used in the planning of the renovation measures. The aim was to find and localize possible defects, subsurface structures and thermal bridges by thermal scanning. The renovation works are still in progress, and the performance of completed buildings will be confirmed by the same type of measurement set.

Palazzo Monte dei Pegni is situated on the principal square of the historical center. In this building, which was of residential use, 4 flats and one office were measured. The measurements included CO_2, indoor temperature, RH and pressure drop between indoors and outdoors. The room spaces had slightly negative pressure drop compared with outdoors' (measured from the level 1.5 m from the floor); the pressure difference varied between -1 Pa--3 Pa. Variation of indoor temperatures: 13 °C – 23 °C (the lowest indoor temperature was in the office, not occupied at that moment); CO_2-level: 620 ppm (the office) – 1100 ppm (depending on the persons inside the apartment); RH-level: 27%-44%. The indoor temperature depended on the control of the heating system.

Some investigations have concerned the north and the east side of one of the examined buildings, called *Monte dei Pegni.* The building was an apartment building, but it is planned to change to residential and office uses. The building had a natural ventilation system and water circulation based radiator heating system, partially fan coils. The measurements showed that the exterior wall structures varied a lot also in the case of the same buildings. Subsurface constructions, covered openings, thermal bridges, uneven structures, etc., were found (Fig. 4). Some of these findings must be taken into account in the renovation design (Figs. 9-13).

The thermal scanning must be done before the sun

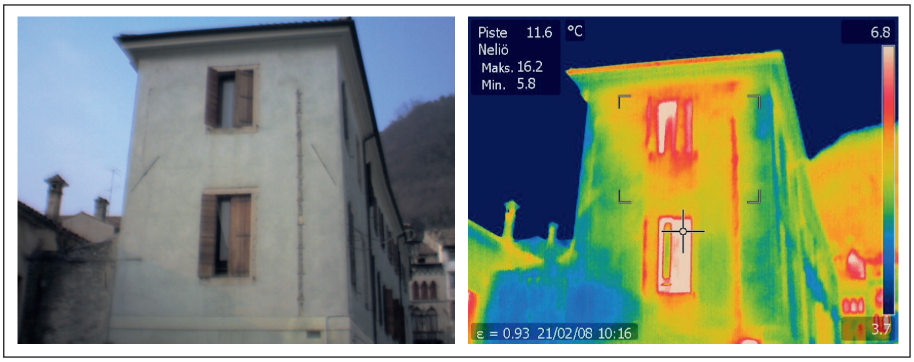

FIGURE 9 Thermal image applied to detect discontinuities beneath the surface, using an inclusive range among 3.7° and 6.8° for the thermographs staircase. It is possible to see a different superficial temperature of materials for that heated places internally
Source: ENEA and VTT elaborations

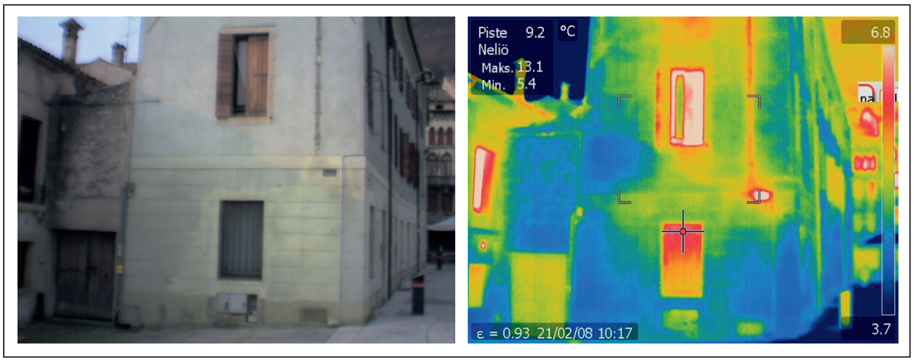

FIGURE 10 Moisture distribution and moisture growth detected by thermal scanning
Source: ENEA and VTT elaborations

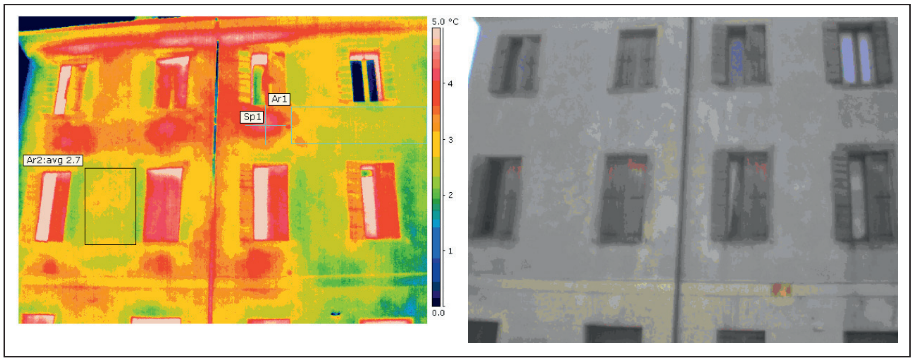

FIGURE 11 The upper part façade in the morning, before sunrise. The radiators and also the intermediate floors, walls, both pipelines are visible
Source: ENEA and VTT elaborations

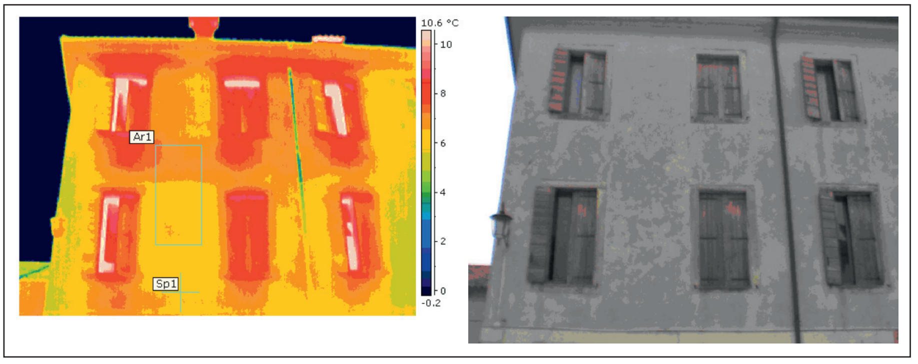

FIGURE 12 The same façade during sun radiation. The external heat source removes the structural details
Source: ENEA and VTT elaborations

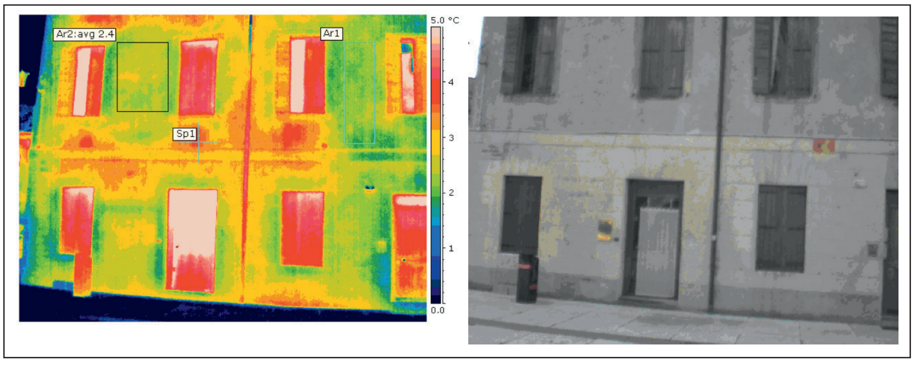

FIGURE 13 Lower part of the façade in the morning. The earlier door place can be seen between the window and the door
Source: ENEA and VTT elaborations

begins to affect the surfaces. The measurements can be repeated during the heating up period and then during the cooling down period – during heating and cooling delamination structures and different structural elements can be seen, depending on the differences of thermal capacities.

Indoor measurements showed temperature variations on the surfaces. Thermography allows to check the condition of radiators and windows. The thermal conditions of external walls varied, and the thermal performance was not uniform. Retrofit of historical buildings means a challenge if there is no possibility to have any additional external insulation. If internal insulation is used, it will decrease the floor a little bit but will increase the effect of thermal bridges in the joint of floors and walls, also in the joint of intermediate walls and exterior walls. By comparing the results of outdoor and indoor scanning, one can decide for renovation needs. The change / repair of windows may be the most efficient measure. The ventilation and heating systems must be totally renovated, which means mechanical ventilation with heat recovery (installation problems), or less effective mechanical ventilation, or hybrid solutions.

Conclusions

Improving the energy efficiency of valuable cultural heritage targets and areas is a challenging task in more ways– the goal depends on the possible planned new use, or use of the building, the actual condition of the building, the performance of the target, the indoor environment and many other factors. There are certain limitations for refurbishment, especially dealing with façades and interiors. But historic building should meet the requirements and not have any health hazards or structural risks. In most cases historic buildings have defied the pressure of centuries and changing times – but the performance of the buildings must be assured.

The historic buildings and also historic centres must be submitted to holistic studies, in which both the building structures and the building systems will be considered.

In the case of energy efficiency it means:

- How the heating system could be renovated or modernized
- How the ventilation system and indoor environment can be improved
- How the cooling system can be improved or added to the existing one
- How to improve the energy efficiency of the historic building envelope

Energy efficiency cannot be improved just focusing the measures on one system only, therefore the most essential thing is to have a holistic view and to try integrating the different systems affecting on historic building performance so that they can interact in an optimal way. This requires first that both the survey of the building conditions and the energy performance of the building have been audited (condition and energy assessment). Then the next step is to have conclusions about the actual performance of the building and the investments needed; it also means that the project requirements and the key performance indicators have to be properly set. It is very important that, except the renovation measures, also the need of facilities and energy management are taken into account. This implies that the performance requirements are set, and on the other hand, one must know what indicators must be monitored.

Using building automation systems (BAS), building energy manage systems (BEMS) and facility management tools means:

- new instrumentation and sensors; (*what can't be measured, can´t be managed!*)
- monitoring and reporting systems, and procedures based on the automation systems and measurements.
- feedback of the results

Improving the facility management system necessarily implies:

- the short- and long-term maintenance procedure.

The paper is also intended to open the discussion about some innovative applications of IR automation thermography and other NDT-methods for cultural heritage buildings. In this project there was no possibility to make larger thermography surveys in different weather conditions. The next test will be made when all the buildings are renovated. Thermography is just one tool of the NDT toolbox and NDT- and NDE-methods (non-destructive testing, non-destructive evaluation) are just a part in the condition and energy assessments of buildings. Anyway, the essential topic is that the performance of historic buildings has been verified by various methods for evaluating the retrofit measures needed.

The effective and proper use of thermography needs a lot of research and development work so that the procedures could be applied more widely. Thermography can be used in detecting the moisture distribution; also some structural deviations can be determined. Both types of damage can be detected by using dynamic thermography applications. Thermography, however, is one tool in NDT-toolbox, and more attention should be paid to combine various methods. In any case, in evaluating the thermal performance of the historic building envelopes, thermography and additional supporting methods, such as air-tightness measurements, heat flux measurements, etc., are the only covering techniques to give a full-scale conception of the performance.

The moisture distribution and some subsurface structures should be found for the future planning and refurbishment measures – in some cases the variations in exterior walls can be critical, e.g., in earthquakes.

One difficult task is to find out how the thermal performance of exterior walls could be improved. The walls are massive, even the U-value is low, there is not so much to do if we want to maintain the façades in the original form. New surface treatments through multi-functional materials, such as thin composites nanostructure insulators, spray or paints, could improve thermal mass, self-cleaning and fire resistant behaviour of the historic buildings, thus contributing to cultural heritage conservation, restoration and rehabilitation. In this direction, research will have another frontier to overcome.

The air-tightness of walls, and especially of windows and doors, is a very crucial factor in energy efficiency – uncontrolled leaks mean uncontrolled ventilation, the share of which can be as significant or even greater than the controlled part of ventilation. Air leaks can be located by thermography and the air tightness of the whole, or part, of the building can be measured by the airtightness test (blower-doors).

References

[1] Kauppinen T. (2009). *"The Use of Thermography in Energy Performance of Buildings directive"* (EPBD)-applications. Thermosense XXXI Proceedings, Bellingham, WA.

[2] Avdelidis N.P., Kauppinen T.T. (2009). *"Thermography as a tool for building applications & diagnostics"*. Thermosense Proceedings, Bellingham, WA.

[3] Fanou S., Kauppinen T. (2009). *"Indagini sul comportamento termico post-operam di un edificio scolastico"*, Atti Conferenza Nazionale sulle Prove non Distruttive, Monitoraggio e Diagnostica, Roma.

[4] N. Avdelidis, C. Catsanedo, E. Cheilakou, C. Ennaceur, S. Fanou, T. Kauppinen, M. Koui, X. Maldague, E. Saarimäki, Transient thermography tools for NDT & E of composites. NDT Conference, Canada 2009.

[5] N.P. Avdelidis, A. Moropoulou, *"Emissivity considerations in building thermography"*, J. Energy & Buildings 35(7), (2003), pp. 663-667.

[6] N.P. Avdelidis, A. Moropoulou, *"Review Paper: Applications of infrared thermography for the investigation of historic structures"*, J. Cultural Heritage 5(1), (2004), pp. 119-127.

[7] N.P. Avdelidis, A. Moropoulou, D. Stavrakas, *"Detection and quantification of discontinuities in building materials using transient thermal NDT techniques: modelling and experimental work"*, J. Materials Evaluation, 64(5), (2006), pp. 489-491.

[8] Fanou S., Tati A., Labia N., Colucci A., Di Biaggio F., Di Sarcina C., Maso R., Martini E., Bartoccini P., Lazzaroni F., (2009). *"L'impegno ENEA per il Patrimonio Culturale – L'attività sperimentale del progetto Vittorio Veneto"*, Rapporto Tecnico ENEA 65/08, pp. 1-41.