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Integrated methodologies energy efficiency of historic buildings

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Abstract

For several years, Italian associations and research organizations have been developing strategies aimed at evaluating and increasing energy efficiency in historic buildings, offering a sort of guidelines about this issue. These strategies are intended to provide useful information for a correct approach to the energy retrofit of historic buildings, offering a framework as well as innovative technical solutions for integrated design intervention restoration of historic buildings. The purpose of the guidelines is investigating the relationship between architectural restoration and plant installations, which are – now – rarely explored problems theoretically and experimentally, by introducing the concept of improvement instead of adapting to the standards of safety and comfort, in accordance with the integrated conservation strategies (Amsterdam Declaration, 1975). Effective proposals of a historic building energy retrofit (or a cultural landscape) can be implemented in a conscious way, tending to an architectural and landscape integration, without changing the monumental building, as it often happens in the case of adaptation of a new building to the new rules. The proposed methodology is based on an interdisciplinary approach, articulated in successive phases: analysis of plant systems, measurements of environmental quality, identification of vulnerabilities, defining appropriate intervention techniques, verification of the improvement achieved. The case study concerns a historic building in Salerno (Italy) dating back to the eighteenth century, used as a school complex. It will be investigated by the morphological, technological, static, energy point of view, by the use of a BIM platform, in order to identify energy efficiency measures consistent with the technological and structural aspects. The objective is, therefore, to identify an integrated methodology of energy retrofit of historic buildings.

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Keywords: Historic buildings; integrated approach; sustainability; reversibility; BIM

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1. The problem of energy consumption of the historic buildings[†]

The study concerns the analysis of a historic school building, situated in Salerno, built in 1929 by engineers de Angelis and Giordano (Fig. 1). The city of Salerno, the capital of the Campania province, is a typical Mediterranean reality in Southern Italy, which stretches between the slopes of Monte Bonadies and the Tyrrhenian Sea in an area of about 60km². The city has about 135.268 inhabitants (Istat, 2011). This research started with the aim to propose a retrofit strategy for historic buildings. Italy has got about 11millions of buildings, reported by "ENEA, October 2010" and 8% of this heritage is of historical interest. The Ministry of Economic Development (MiSE 2016) analysis on public consumption estimates an energy-intensive of about 46.619 Mtoe[‡] each year.

The legislation (Legislative Decree 102/2014, implementing Directive 2012/27 / EU of the European Parliament and the Council, through the criteria dictated by European Delegation Law 96 of August 6th, 2013) sets out the measures for the promotion and improvement of energy efficiency, for achieving national savings target: "reduction, by the year 2020, 20 million tons of oil equivalent of primary energy consumption, amounting to 15.5 million equivalent tons of final energy fuel, counted since 2010, in line with the national energy strategy. "in addition, with regard to the properties of the Public Administration, the decree establishes an obligation to "achieve the energy upgrading of at least 3 per cent yearly of the indoor air-conditioned floor area or, alternatively, lead to a cumulative energy savings in 2014-2020 of at least 0.04 Mtoe." So, the Italian national trend is moving to define the most appropriate strategies to achieve energy savings results expected and, for the first time ever, it opens application scenarios to historic buildings, a strong presence in the *country*.

(a) (b)

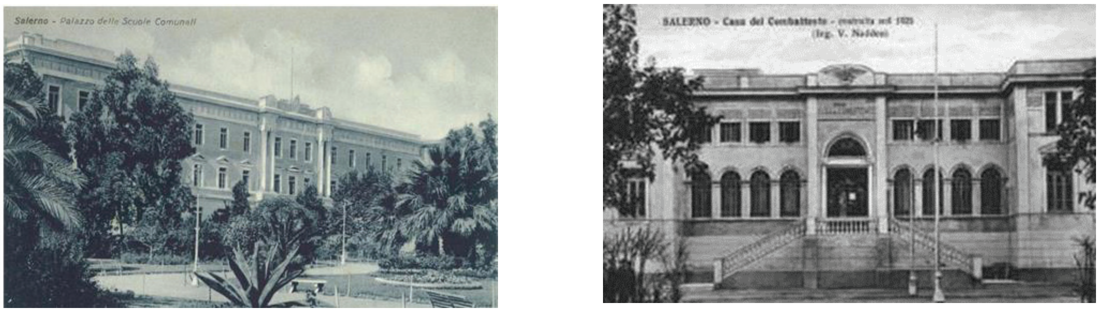
Fig. 1.(a) Territorial location of the school G. Barra; (b) View of the building Barra. Source: "*The reinforced concrete slabs of the early twentieth century in Salerno. forms of degradation and for the recovery addresses*". Ing. R. Del Regno.

In order to meet these needs, the MiBACT has drafted the "GUIDELINES FOR THE IMPROVEMENT OF ENERGY EFFICIENCY IN THE CULTURAL HERITAGE", a tool for designers and administrative staff engaged in the field of energy rehabilitation of historic buildings. These guidelines show a range of architectural restoration projects involving the use of innovative, less invasive and more performing materials and technologies, a respectful character of the building historicity. Among the most valid technologies heat-reflecting insulating materials, with a low emissivity that reflects up to 60% solar radiation the thermal insulating plasters, the vacuum insulation panels, etc. are emerging.

[†] Elaborated by Anna Sessa
[‡] Mtoe (mega tonne oil equivalent)

2. The architecture of the early twentieth century in Salerno[§]

The building investigated, although not listed for its special architectural interest, is an artifact of historical interest and has architectural and structural features to the buildings made in Salerno in the first '900. It dates back to the first decades of the twentieth century, when Italy experienced the spread of the fascist regime which promoted the realization of two kinds of buildings: the central government representative one (Beam Houses, Podesta's Office, etc.) and the public function one (schools, hospitals, nursing homes, etc.). Salerno, a small city invested by a dynamic growth due to the strong industrial presence, became the object of a profound urban makeover that saw the birth of a series of buildings among which the "House of the fighter" 1925, Eng. V. Naddeo, and the Palace of the "Western Schools" 1929, Eng. M. De Angelis and C. Giordano are included.



(a) (b)

Fig. 2. (a) House of the Fighter, Ing. Naddeo, 1925, Elea source, UniSa. University Library System; (b) Salerno, Palace of the Municipal Schools, Salerno, photos of Vincenzo Cattaneo, after 1925, Elea source, UniSa. University Library System.

3. Analysis of the current state of the building

Today, the school building houses the primary and nursery schools "Gennaro Barra" and the hotel vocational school "Virtuoso" (Fig. 3). It consists of three floors and a basement level. The choice of building materials was dictated by local availability: the foundation structure consists of limestone structural masonry (thickness varying between 1.5m and 1.6m), about 3m deep. The external face is in travertine (for the basement and ground levels) and with yellow stone for the remaining two floors. The inter-floor slabs, originally double T metal beams and vaults with Spaccatelle tuff, have been modified while working in favour of the double T metal beams and masonry type, which began to be spread in the early twentieth century (Fig. 4). The envelope is characterized by a wall with a standard thermal transmittance (U= 0,89 W/m2K), that assure a relatively good thermal comfort, in summer.

Fig. 3. First North prospect design hypothesis, "Western school building project for the city of Salerno", in 1908. Engineers M. De Angelis and C. Giordano.

[§] Elaborated by Claudia Sicignano

The old wood frames windows, originally fit for the internal ones and chestnut wood for the external ones, have been recently replaced with PVC frame windows on the SOUTHERN prospectus, and with iron frame ones, on the NORTHERN prospectus. By the comparison between photos 5(a) and 5(b) you can see that the new fixtures have been moved to the outer edge of the façade, radically transforming the statement, both stylistically and geometrically and shading characteristics. The pitched roof, made up "by an armed Pull in pitch-pine wood in the main structures, in wooden sharp-edged spruce in small armors" was covered by interlocking tiles. The floor of the classrooms is constituted by a 3cm thick layer of mixed cement to coarse sand, with extra fine surface layer composed of cement, fine sand and iron red, black or natural oxide, that constitutes the traditional "cement tiles" or "pastries" in a hexagonal cm25x25 shape; in representative corridors and classrooms the floor is made up of the traditional "grits" in marble and cement chips, interspersed with frets typical of the first decades of the twentieth century and verifiable in other buildings of the time within the city.

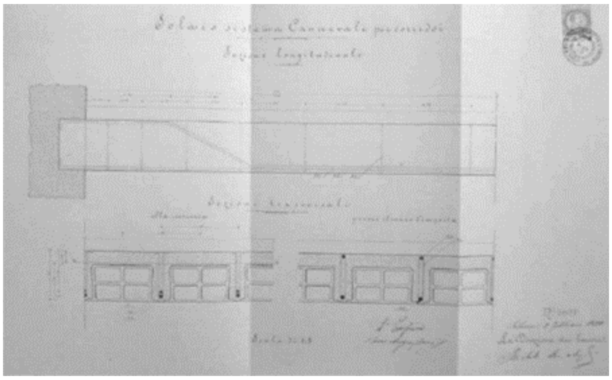
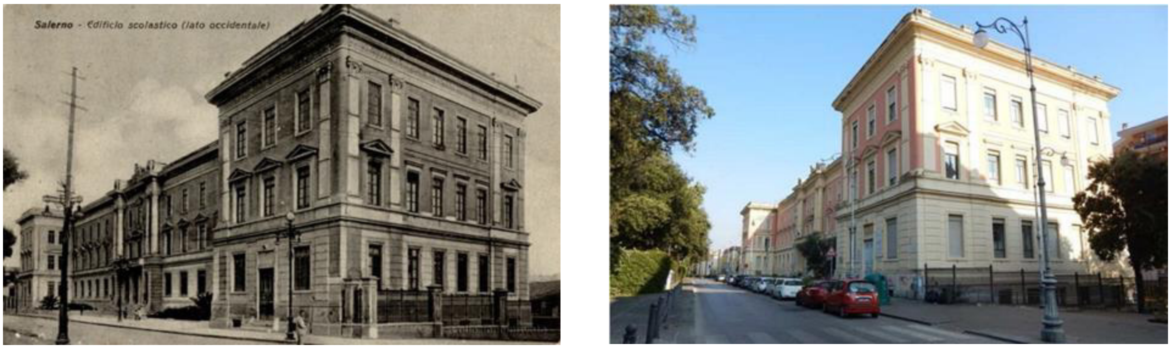


Fig. 4. Engineers Michele De An¬gelis and Carlo Giordano, "Canne¬vale slab system for corridors, lon¬gitudinal and cross sections to the centre line and at the supporting wall", 7th February 1926. Detail of the floor (from Historical Archive of the City of Salerno - ASS. X - XIII - 223).

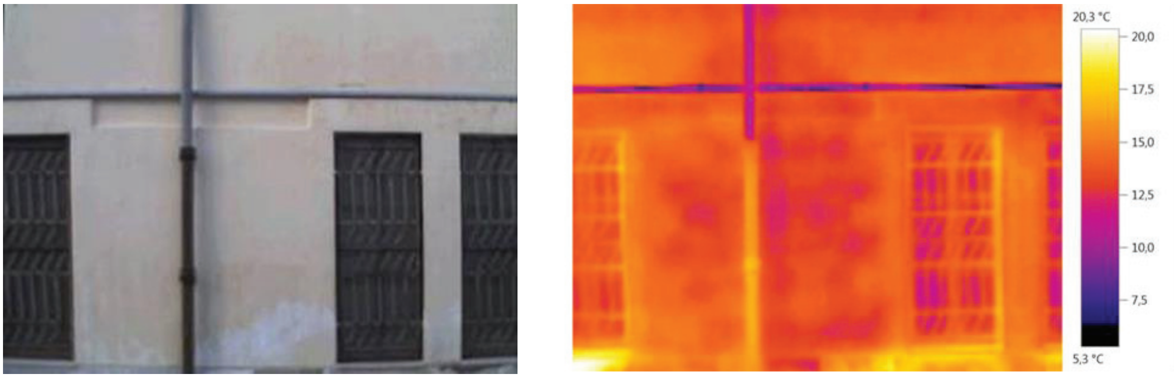


(a) (b)

Fig. 5. (a) Current elevation view North; (b) North elevation view, Elea source, UniSa. University Library System

The diagnostic phase has provided photographic and thermographic campaigns (Fig. 6). The data were processed with TERMUS software, based on a diagnostic algorithm calibrated on the latest legislation, allowing the energy audit of the school complex. By the analysis the following results have been carried out:

- Energy class **D** building;
- Global performance index referred to non-renewable sources:189 kWh / m² year (Fig.7);



(a) (b)

Fig. 6. (a) Plaster degradation, Northern prospect, due to capillary rise of moisture; (b) The thermal image shows the phenomenon of moisture by capillary rise referred to the interspace in the northern side.

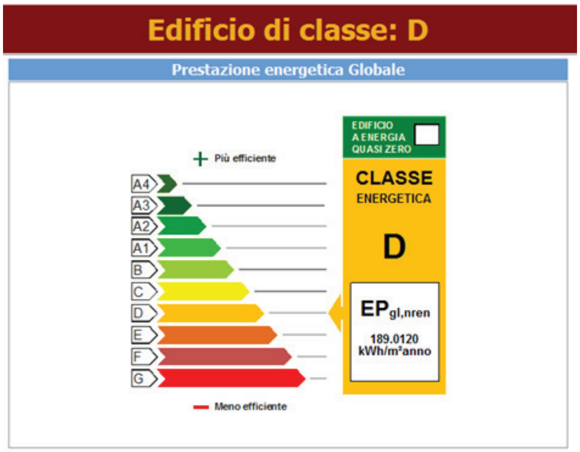


Fig. 7. The overall performance index for non-renewable sources, for the state of affairs.

4. Proposed interventions**

The proposed interventions on the building are divided into two categories:
- Recovery and rehabilitation;
- Redevelopment.

The recovery and rehabilitation efforts include:
- Repairing the roof slab with thermal insulation and waterproofing (Fig.8a);
- Recovering the interspace ventilation, on the lower level, which causes infiltrations and mold formations on the basement walls (Fig.8b);
- Removing rising moisture through an intervention of chemical cut with water-repellent resin injections. At the end of such intervention the expected results are the following ones:

** Elaborated by Giacomo Di Ruocco

• Energy class C building;
• Global performance index referred to non-renewable sources:155 kWh / m²year;

4.1. Energy improvement interventions

After making the above recovery and rehabilitation efforts, and attesting the achievement of the performance improvements, we can evaluate the assumptions aimed at upgrading the energy efficiency. The software, used for energy certification, highlighted the failure to meet the minimum requirements of thermal transmittance, prescribed by the regulations. In order to improve the energy performance envelope, we have considered different combinations of technical solutions, always in agreement with the preservation of the historic building.

(a) (b)

Fig. 8. (a) Infiltration due to the rainwater to the roof slab; (b) Infiltration due to rainwater rebound, with mold and condensation. Wall basement, Northern prospect.

We decided to take specific action on inter-floor slabs and outer walls, through the combinations set out in Table 1:

Table 1. Combinations of envelope improvements.

<table>
<tr><th></th><th colspan="3">Combinations of envelope improvements for energy efficiency</th></tr>
<tr><td>interventions to the floor</td><td>thermal plaster with perlite and PVC particles</td><td rowspan="2">thermal plaster made of NHL 3.5 lime</td><td>airgel plaster</td></tr>
<tr><td>interventions to outer walls</td><td>Wood fiber panels</td><td>airgel panels</td></tr>
</table>

4.2. Characteristics of the chosen materials

Frame

The choice of the fixtures comes from a careful analysis of the characteristics of the original artefact. It has been preferred the use of profiles in natural materials like wood and Corten steel. The hardwood frame has been analysed since it recalls the original materials, though: it needs sections of thicker profiles, it is not well-tolerated in the marine environment and it needs more maintenance. The selected type has a frame with 56x70 mm section with two thermo-acoustic seals and wooden drip. The door profile has got a 58x70 mm section with triple battens and handling by means of 14mm diameter steel hinges and 4mm glazing.

Technical / performance features of wooden frames

Thermal transmittance Uw = 1.4 W / m²K; Soundproofing power Rw = 38 dB; Air permeability: Class 4 (EN 1026, UNI EN 12207); water tightness: Class E750 (EN 1027, UNI EN 12208); Wind resistance: class C4 (EN 12211, UNI EN 12210). Corten steel is a high-resistance self-passivating alloy containing copper, chromium and phosphorus, characterized by a high resistance to corrosion and tensile stress. This alloy has the property of self-protection by means of the formation of a surface film that prevents the progressive spread of the corrosion. The alternative of the Corten steel frame has the benefits of being able to use slender profiles to the advantage of the glass area percentage, of requiring less maintenance, especially relative to handling systems and of better adapting to the marine environment. The chosen type is a window frame having inner and outer overlapping with view sections of 47 mm for the lateral junction and of 62 mm for the central one. For the subdivision of the frame glasses, the system provides a thermal break profile with visual clutter of 36 mm. The sealing characteristics are guaranteed by an open joint system with a central gasket seal and a batting one inside. There is a double 4mm glazing.

Technical / performance characteristics of corten steel frames

Resistance to wind load - Test pressure: 4

Resistance to wind resistance - frame bending: C

Watertight: 8 °; acoustic performance (with Rw per IGU 42 dB): 43 (-1; -4) dB; thermal transmittance (with Ug glass 1,0 W / m2K) = 1.60 W / m²K; Air permeability: 4.

Thermal-plaster with perlite and PVC particles

Plaster of continuous fund for facades and interior walls, breathable and highly insulating. Consisting of cement, common lime, additives to improve workability, perlite and EPS lightweight aggregate. According to UNI EN 998-1, with resistance values to vapor diffusion μ (EN 1015-19): 20 and thermal conductivity λ10, dry (EN 1745: 2002): 0.074 W / mK (tabular value) per P = 50 %.

Panels in wood fiber

The wood fiber panels chosen to achieve an internal coat are waterproof and breathable, with performance characteristics as early as the 4cm thickness. They have resistance values to water vapor diffusion μ (EN 1015-19): 5 and thermal conductivity λ10, dry (EN 1745: 2002): 0.039 W / mK (tabular value) per P = 50%.

Thermal-plaster of NHL 3.5 lime

The thermal-plaster based on natural hydraulic NHL 3.5 lime and expanded glass is CE marked according to the UNI EN 998-1 and is ANAB-ICEA certified for green building. It is a material with good performance characteristics, but at the same time both breathable and insulating already in reduced thicknesses and respects biological compatibility criteria. It shows resistance values to water vapor diffusion μ (EN 1015-19): 10 and thermal conductivity λ10, dry (EN 1745: 2002): 0,086W / mK (tabular value) per P = 50%.

Plaster and airgel panels

Aerogel is an innovative material, used in the past in aerospace. Today, the use of this material is strongly spreading in building. The chosen panel is flexible, formed by a layer of silica airgel reinforced with PET fibers (felt), water-repellent and breathable, supplied in 140x72 cm panels, for a 10mm nominal thickness with bulk density of 190 kg / m³, resistance to water vapor diffusion μ (EN 1015-19): 5, thermal conductivity λ10, dry (EN 1745: 2002): 0,015W / mK (tabular value) per P = 50%.

The heat-insulating plaster is made of NHL-Aerogel and is recommended for green building. This product has been chosen as it is suitable for very porous masonry and consists of the following basic materials: natural hydraulic lime - NHL according to EN 459-1, common lime, white cement, airgel granules, inert light mineral, organic binders <5%, additives to improve workability. It shows resistance values to water vapor diffusion μ (EN 1015-19): 5 and thermal conductivity λ10, dry (EN 1745: 2002): 0,028W / mK (tabular value) per P = 50%.

The chosen combinations for which we carried out the evaluation of the global performance index relative to non-renewable sources are the following ones: Combination 1: Corten steel fixtures, 3cm thick thermal-plaster with perlite and PVC particles on intermediate floors and 4cm thick wood fiber panels the walls; Combination 2: wooden window frames, 3cm thick thermal-plaster with perlite and PVC particles on inter-floor slabs and 4 cm wood fiber panels on the walls; Combination 3: Corten steel fixtures, 3cm thick insulating plaster made of NHL lime 3.5 for walls and inter-floor slabs (Fig. 9); Combination 4: wooden window frames, 3cm thick insulating plaster made of NHL 3.5 lime on walls and inter-floor slabs; Combination 5: Corten steel fixtures, thermal insulating airgel panels of silica reinforced with PET fibers (felt), 1cm thick on walls and 1 cm thick insulating render in NHL-Aerogel on inter-floor slabs (Fig. 10); Combination 6: wooden window frames, insulating Aerogel panels of silica reinforced with PET fibers (felt), 1cm thick on the walls and insulating NHL-Aerogel render, 1cm thick on inter-floor slabs.

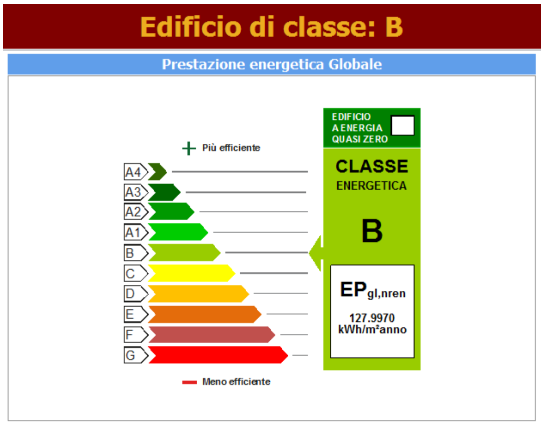


Fig. 9. The overall performance index for non-renewable sources, post intervention of energy upgrading with steel frames Corten, plaster NHL lime-based insulating 3.5 3cm on the walls and on the floors between floors.

Fig. 10. Overall performance index relative to non-renewable sources, post energy upgrading with corten steel fixtures, insulating airgel panels, 1cm thick on the walls and insulating airgel render 1cm thick on inter-floor slabs.

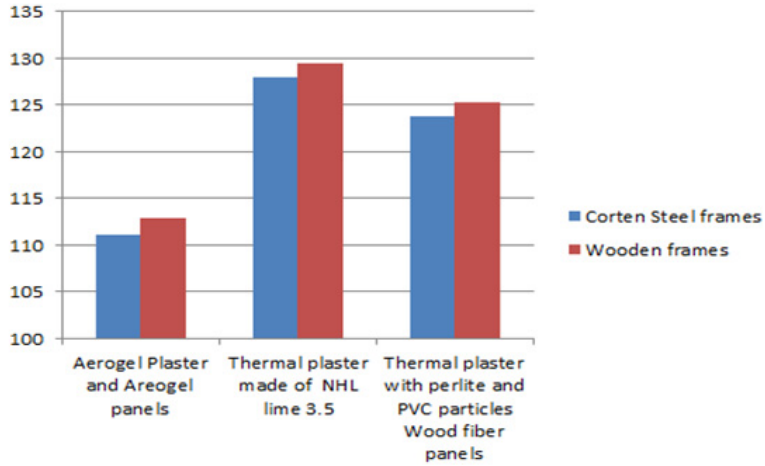


Fig. 11. Trend of overall performance index for energy retraining interventions.

4.3. Achievements

The global performance index assumes the values reported in the table 2, for the different combinations proposed.

Table 2. Values of global energy class.

		Combinations of energy efficiency			
	interventions on the floor	Aerogel plaster	thermal plaster made of NHL lime 3.5	thermal plaster with perlite and PVC particles	
	interventions on outer walls	Aerogel panels		Wood fiber panels	
Frames type	Corten Steel frames	110,99	128,00	123,75	Global non-renewable Energy Performance Index [kWh/m²year]
		B	B	B	Global Energy Class in Control building
	Wooden frames	112,82	129,45	125,32	Global non-renewable Energy Performance Index [kWh/m²year]
		B	B	B	Global Energy Class in Control building

155	Global non-renewable Energy Performance Index related to the building subject of restoration and rehabilitation [kWh / m²year]

For every combination it is possible to detect a percentage saving over the basic building and the rehabilitation object building as reported in table 3.

The results show that the greatest savings rate, in terms of kWh / m² year, can be got by the 5 and 6 combinations. But we must take into account the price of the chosen materials. Considering that fixtures prices are comparable as even if the raw material has an uneven cost - this expenditure is balanced over time by different maintenance needs - you have to analyse the prices of inner finishes for slabs and outer walls. As for the 5 and 6 combinations the aerogel price is about 50 Euros / m² for supply and installation. The cheapest combinations are 1 and 2 (wooden fibre panels and perlite and PVC thermal-plaster) with materials price of about 8 euros / m² for supply and installation, but the performance features are far lower, especially for combination 2. The 3 and 4 combinations associate intervention cheapness, with a materials price of about 12 Euros / m² for supply and installation, to a high performing yield.

Table 3. Values in percentage of energy savings.

			Combinations of energy efficiency			
		interventions to the floor	Aerogel plaster	thermal plaster made of NHL lime 3.5	thermal plaster with perlite and PVC particles	
		interventions to outer walls	Aerogel panels		Wood fiber Panels	
Frames type	Corten Steel frames		110,99	128,00	123,75	Global non-renewable Energy Performance Index [kWh/m²year]
			29,50%	18,17%	20,98%	Savings percentage over the building subject of restoration and rehabilitation
	Wooden frames		112,82	129,45	125,32	Global non-renewable Energy Performance Index [kWh/m²year]
			28,28%	17,20%	19,95%	Savings percentage over the building subject of restoration and rehabilitation

4.4. Conclusion

It is convenient to take appropriate action in the combination 3, with respect to which there has been:

- An improvement of 18, 17% of the energy performance characteristics respect to the building subject of restoration and rehabilitation;
- A saving of 27 kWh / m²year which, for an area of 4300m², corresponds to an overall saving of 116,100kWh / year.

The overall performance goes from a consumption of 189 kWh / m²year for energy class D to a consumption of 155 kWh / m²year for energy class C; so it results to be 27 kWh / m² year which, for an area of 4300m², involves a saving of 146,200 kWh / year.

5. Financial evaluation

Energy results were compared from a financial point of view.

The table shows the evaluation of energy savings (Euro) compared to the investment cost (Euro). The main indices used in the financial evaluation are Net Present Value (VAN) and Internal Rate of Return (TIR). The VAN shown in the table is negative because the investment is not recovered in the 25 years of Analysis. With a negative VAN is impossible to calculate TIR. The most convenient combination is wooden fiber with wooden frames with a VAN of -200.713Euro, so the less convenient one is Aerogel plaster and panels with Corten Frames with a VAN of -925.191Euro.

Table 4 the comparison from a financial point of view.

technical and economic parameters		Starting characteristics	Results consequent intervention of recovery and rehabilitation	Results consequent intervention of energy retrofit (Aerogel + cor-ten frames)	Results consequent intervention of energy retrofit (Aerogel + wooden frames)	Results consequent intervention of energy retrofit (Biocalce+ cor-ten frames)	Results consequent intervention of energy retrofit (Biocalce + wooden frames)	Results consequent intervention of energy retrofit (Fibreboard + cor-ten frames)	Results consequent intervention of energy retrofit (Fibreboard + wooden frames)
energy classification	Classe	D	C	B	B	B	B	B	B
Index of non-renewable global energy performance [kWh/m²year]	Epgl,nr	189,01	155,26	110,99	112,82	128,00	129,45	123,75	125,32
fuel requirements - GPL [kWh]	CMB2	693.263	558.291	380.552	387.933	448.836	454.668	432.554	438.100
cost of fuel- GPL [€]	P2	97.057	78.161	53.277	54.311	62.837	63.654	60.558	61.334
electricity needs [kWh]	Qx_rete	28.840	28.460	28.360	28.364	28.399	28.402	27.976	28.393
electricity costs [€]	P4	6.345	6.261	6.239	6.240	6.248	6.248	6.155	6.246
Savings in total energy consumption from the building subject of recovery and rehabilitation [€]	R3		18.980	24.905	23.871	15.337	14.520	17.710	16.841
Savings in total energy consumption from the building subject of recovery and rehabilitation [%]	r3		0,00	29,50	28,28	18,17	17,20	20,98	19,95
investment cost			237.556	1.770.042	1.007.500	1.352.283	589.741	1.214.148	451.606
VAN [€]				**-925.191**	**-505.501**	**-760.217**	**-337.345**	**-622.838**	**-200.713**
TIR [%]				-	-	-	-	-	-

References

[1] "Guidelines for energy efficiency improvements in the cultural heritage - Architettura, centri e nuclei storici ed urbani", MiBACT, 2015

[2] M. De Angelis, C. Giordano, "Design of the new Western school building for the city of Salerno. Report for the choice of soil", 1908, Elea Unisa platform (University of Salerno).

[3] "CENSUS ISTAT 2011", 2011, ISTAT

[4] "CRESME SAIENERGIA relationship", 2010, CRESME su elaborazione dati ENEA.

[5] R. Del Regno, "Reinforced concrete floors in Salerno in the early XIX century", PhD thesis in Building and Urban Renewal, University of Salerno, 2012.

[6] V. Pracchi, E. Lucchi, "Energy efficiency and built heritage. The challenge of improving the performance of historic buildings", Maggioli Editore, 2013.

[7] V. Dodaro, "Salerno during the Fascist period: the public buildings, social housing, urban planning", Salerno 1997.

[8] S. D'Auria, E. De Feo, G. Di Ruocco, Parametric planning for the restoration and rehabilitation of the architectural heritage, CSE Journal - City Safety Energy, Issue 2-2014, July-December, Le Penseur, Brienza, pp. 107-118. ISSN print edition 2283-8767, ISSN online edition 2284-3418.

[9] G. Di Ruocco, "Innovative non-invasive strategies for the energy efficiency of historic buildings", p. 1-150, FISCIANO: CUES, 2014, ISBN: 9788897821717

[10] G. Di Ruocco, "The energy retrofit in the recovery of historic center", in Colombo L. (eds). CITY ENERGY. Naples, 20 to 21 January 2012, p. 267-276, BRIENZA: Le Penseur, ISBN: 9788895315171