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Methodology for energy retrofitting of Modern Architecture. The case study of the Olivetti office building in the UNESCO site of Ivrea

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ABSTRACT

Latest European Union programs related to energy efficiency underline the need for retrofitting existing buildings, which are responsible for 40% of EU total energy consumption. Accounting for almost 45% of the existing building stock, the architecture of the second half of the twentieth century represents one of the main targets, becoming a vulnerable category despite its heritage value. This consciousness clarifies the urgent need of developing a new Methodology for Energy Retrofitting of Modern Architecture (MERMA), capable of integrating thermal improvement with architectural preservation. This paper aims to demonstrate the legitimacy of both issues, which share, essentially, the same concerns: supporting a sustainable development by preserving non-replaceable resources, natural or cultural as they are. The MERMA is a cohesive general methodology, based on an interdisciplinary approach. It starts from the architectural and technological inquiry, includes the energy analysis and different project proposition, and uses evaluation matrices to outline the most suitable intervention strategy. As an applicative case study, the first Olivetti office building (1963), by the architects Bernasconi, Fiocchi, and Nizzoli, is chosen. It is located in the industrial site in Ivrea, recently registered in the UNESCO World Heritage List and protected by the Italian law on heritage monument DL 42/2004. By means of the MERMA application, a reduction of 55% of the building's energy demand is assured, ensuring the fulfilment of all regulations' standards, avoiding any derogation, and preserving its heritage value. For high-quality or recognized II post-war building stock, combined energy-saving and heritage preservation is justified and proposed, instead of the sole energy retrofitting commonly applied today.

1. Introduction and background

Existing buildings are central elements in the European Union's energy efficiency policy, as they account for nearly 40% of final energy consumption and are responsible for approximately 36% of all CO_2 emissions [1–3], primary drivers of climate change [4–6]. The 2015 Paris Agreement boosts the Union's efforts to decarbonize its building stock by giving priority to energy efficiency [2], aiming to reduce greenhouse gas emissions by 80–95% compared to 1990 [7].

Accounting for almost 45% of existing building stock [8], buildings of the second half of the twentieth century, especially those dating from the two decades preceding the oil crises of the 1970s, represent one of the main targets [9]. Measures to improve their energy performances are primarily focused on envelope optimization [10,11], achieving high reductions of energy consumption up to 70% [12,13], but without any particular consideration about their architectural quality [14]. Nowadays, the preservation of Modern Architecture is at risk, not only due to invasive retrofitting practices, for instance, the ex-Siemens building in Saint Denis by Bernard Zehrfuss [15], but also to the convenience of rebuilding instead of restoring or developing renovation methods tailored to modern buildings. Integral reglazing, full façade replacement or complete internal redesign are widely accepted actions, often without considering fundamental issues like the materiality preservation or enhancing the urban and cultural value of modern aesthetic. Furthermore, their construction techniques, widely regarded as leaky and poorly insulated, made them especially vulnerable, and difficulties in

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their heritage recognition permitted radical alterations, with insufficient consideration about their real energy potentialities [9].

Only in recent years, researchers have raised and analyzed the topic of combining architectural safeguard and energy retrofitting, assessing the benefits of historical conservation and energy improvement through a single intervention. According to Loli and Bertolin [16], the first contribution in this field was published in 2008, showing how the definition of a methodological approach is still in its early phase [17–19]. Many methodologies focus on specific issues: Ma et al. [20] outline a procedure for cost-optimal retrofits; Ascione, de Rossi, and Vanoli [21] consider energy savings and economic benefits, Adhikari et al. [22] propose a procedure based on energy modelling and performance simulation; Grytli et al. [23] outline a method concerning the environmental impact and the heritage values of the buildings and Fiore et al. [24] define and AHP (Analytic Hierarchy Process), based on a Decision Matrix, for interventions on historical buildings.

These refurbishment methodologies are useful tools that allow to reach sensible improvements in each one of the above-mentioned issues; however, what is lacking today is a cohesive general approach for conducting deep energy retrofits specifically tailored to Modern Architectural heritage. Most of the research deal with historic buildings [22, 24–26], while the highest potential in energy saving can be reached for buildings realized between 1945 and 1990 [4]. Furthermore, no integrated methods have been developed for interventions on light buildings' façades [16,17] and the most recent studies in this field are mainly focused on the thermal issue [27] or need further implementation in their design phases [28]. It must be considered that Modern Architecture curtain walls are often representative of much of the aesthetic and architectural value, and constantly exposed to climate and anthropic-induced decay. Also, the envelopes contribute to large thermal transmittance and account for 20–30% of total energy consumption [29].

This paper aims to define an innovative Methodology for Energy Retrofitting of Modern Architecture (MERMA), capable of integrating thermal improvement with architectural preservation. It introduces measures that allow to preserve the high value of the existing façades while fulfilling all the energy standards. This kind of approach turns out ultimately to be sustainable not only from an environmental point of view but also culturally and economically. An application of the methodology is demonstrated for the first Olivetti office building in the UNESCO site of Ivrea; while the study is conducted on a single building, the goal is that the MERMA can be assumed as a general guideline and applicable to any modern building.

2. Materials and method

2.1. Methodology for energy retrofitting of Modern Architecture (MERMA)

The methodology derives from previous studies conducted by the laboratory of techniques and preservation of Modern Architecture at the Ecole Polytechnique fédérale de Lausanne (TSAM-EPFL) [9]. Its interdisciplinarity comes from the combination of the many particular issues described above [20–24]. The general approach individuated by Ide et al. [30] is also considered. The overall process is structured into five major phases, Fig. 1.

It starts from the architectural inquiry, which includes the geometric, spatial, and functional survey. This is conceived as the first research step, helping the designer to understand the value of the whole building concept. Its main purpose is to acquire extensive knowledge about the building and to identify the original, added and replaced elements. This work is associated with the archives documentary research, examining original drawings, sketches, reports, interviews, and historical photos.

The second step consists in the technological analysis, aiming to study the different envelope's materials, through a deconstruction/reconstruction process. It allows to identify the construction elements, the installation methods, and the assembly processes. The knowledge thus acquired is re-elaborated in technical drawings, at the detail scale (1.20–1.1), showing all the building components.

The third phase of the investigation process consists in the thermal diagnosis in the current state. The purpose is to evaluate the energy consumptions and heat losses through the different façade elements. This step is fundamental to identify the building's weaknesses and define which aspect the retrofitting project will be mainly focused on.

The fourth step is the definition of different intervention scenarios, capable of improving energy efficiency. The variants are hierarchically organized, to show both the thermal and architectural impact on the original building. To reach an adequate detail definition, all projects are developed at least in a 1.20 scale.

The fifth and last step is the variants multicriteria comparison, which is the most diffuse method to rank different options to find a suitable solution [31–33]. Firstly, a graphic comparison is proposed, then the AHP approach is used [34]. An evaluation matrix is compiled, considering not only architectural and energetic aspects but also technical feasibility, heritage preservation, and economic viability. Assigning different scores to each variant, it is finally possible to rank the different intervention scenarios, to select the most effective and appropriate actions [35]. Any in conflict criteria – which create awareness about conservative solutions – can be also identified.

2.2. Case study location and building

To apply the MERMA, the Olivetti industrial city of Ivrea is chosen. This site is selected for multiple aspects, first of all for its high and well recognized cultural value: on the July 1, 2018, it was in fact officially registered in the UNESCO World Heritage List [36], in which only 2% of the assets classified belong to the twentieth century [37].

The methodology is in particular demonstrated for the first Olivetti office building Figs. 2 and 3, conceived between 1960 and 1963 by the architects Gian Antonio Bernasconi, Annibale Fiocchi, and Marcello Nizzoli. The building urgently needs retrofitting interventions and presents a high-value curtain wall, which should be preserved. The

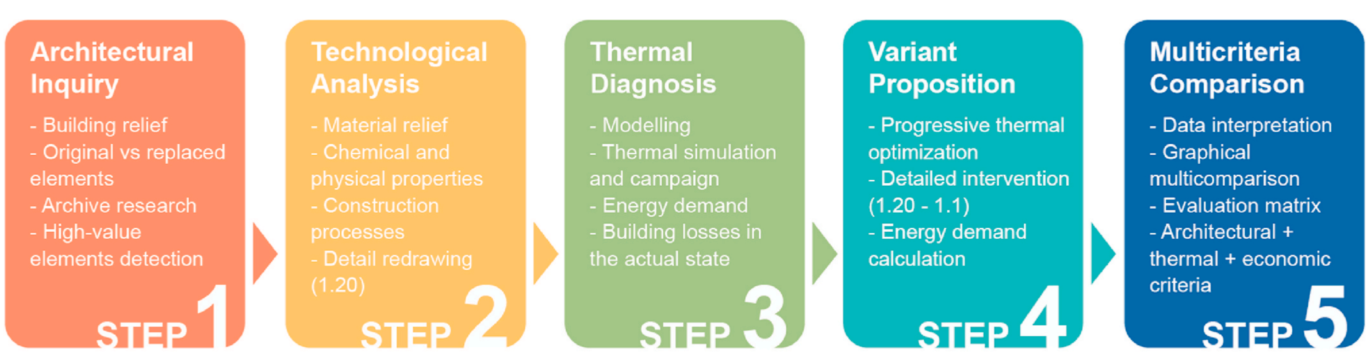


Fig. 1. Key steps of the Methodology for Energy Retrofitting of Modern Architecture (MERMA).

Fig. 2. Aerial view of the building after its construction, 1965.

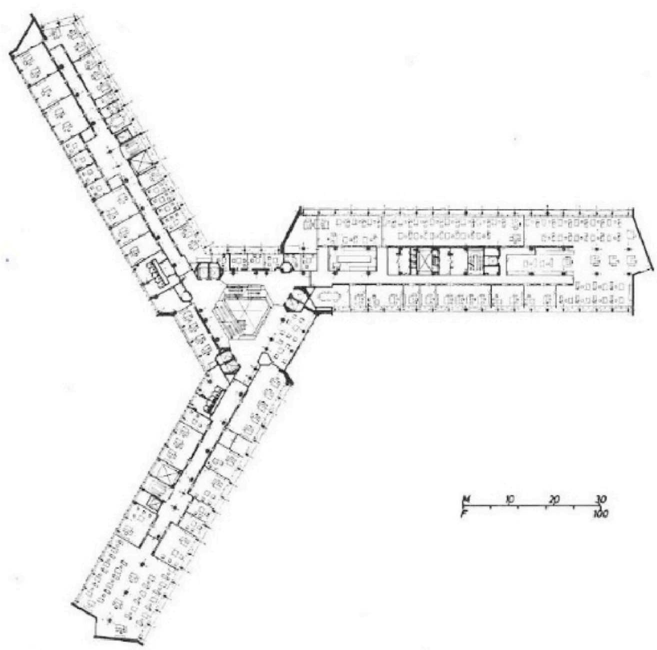


Fig. 3. Typical floor plan of the Olivetti office building.

Table 1
Identifying data of the case study building.

Name		Palazzo Uffici Olivetti
Year of construction		1960–1963
Designers		M. Nizzoli, A. Fiocchi, G. Bernasconi
Localization		Via Jervis, 77, Ivrea (TO), Italy
Functional destination		Offices
Site Altitude	m	253
Tot. height	m	30
Tot. neat floor area	m^2	27.600
Tot. neat volume	m^3	79.500
Total façade surface	m^2	12′500
Windows	m^2	6′800
Glazing	%	64
Roof surface	m^2	4.800
Porch slab	m^2	850

identifying data are summarized in Table 1.

The palace is protected by UNESCO and since 2016 by the Italian law D.lgs 42/2004 [38], which states its status of cultural heritage and sets out its unreplaceable elements: first of all the original aluminum frames.

2.3. Architectural inquiry

The first step starts with archival research. The Olivetti Historical Archives - AASO [39], the archives of the Museum of Modern Art of Rovereto and Trento - MART [40] and the Study Center and Communication Archives in Parma - CSAC [41] were visited, to acquire a complete knowledge about the building's original design and history. Then, a complete geometrical survey was done, accompanied by the conservation of the constructive elements' diagnosis, investigating the origins, the causes, and the possible solutions for the founded alterations [42].

It results that, over the years, the palace maintained a high authenticity level both in materiality and composition. Very few envelopes parts were altered, remaining close to the original project. The only significant alteration consists in the replacement, on the west facade, of the original and transparent Thermopane glasses (U value of 3.0 W/m^2K) with bronze reflecting glasses, type Infrastop (U value of 1.5 W/m^2K), for thermal reasons [43,44].

In particular, among the elements that contribute to define the building heritage value, as already stated by the Italian legislation, the windows' book-opening system is assessed to be unique in the world and not replicable today with any thermal break technology, Fig. 4.

2.4. Technological analysis

The data collected through the detailed analysis of the building technology allow to classify all the envelope materials, according to their physical and chemical properties. This step is particularly important for the third and following phase, when the evaluation of the transmittance U value of all the building elements (such as walls, roof, and floors) is taken into account. According to the MERMA, all the façades and layers structures of the Olivetti palace were redrawn from scale 1:20 to 1:1, as shown in Fig. 5, to fully understand the adopted technology and to propose the most appropriate intervention, in terms of materials and dimensions, according to the required performances.

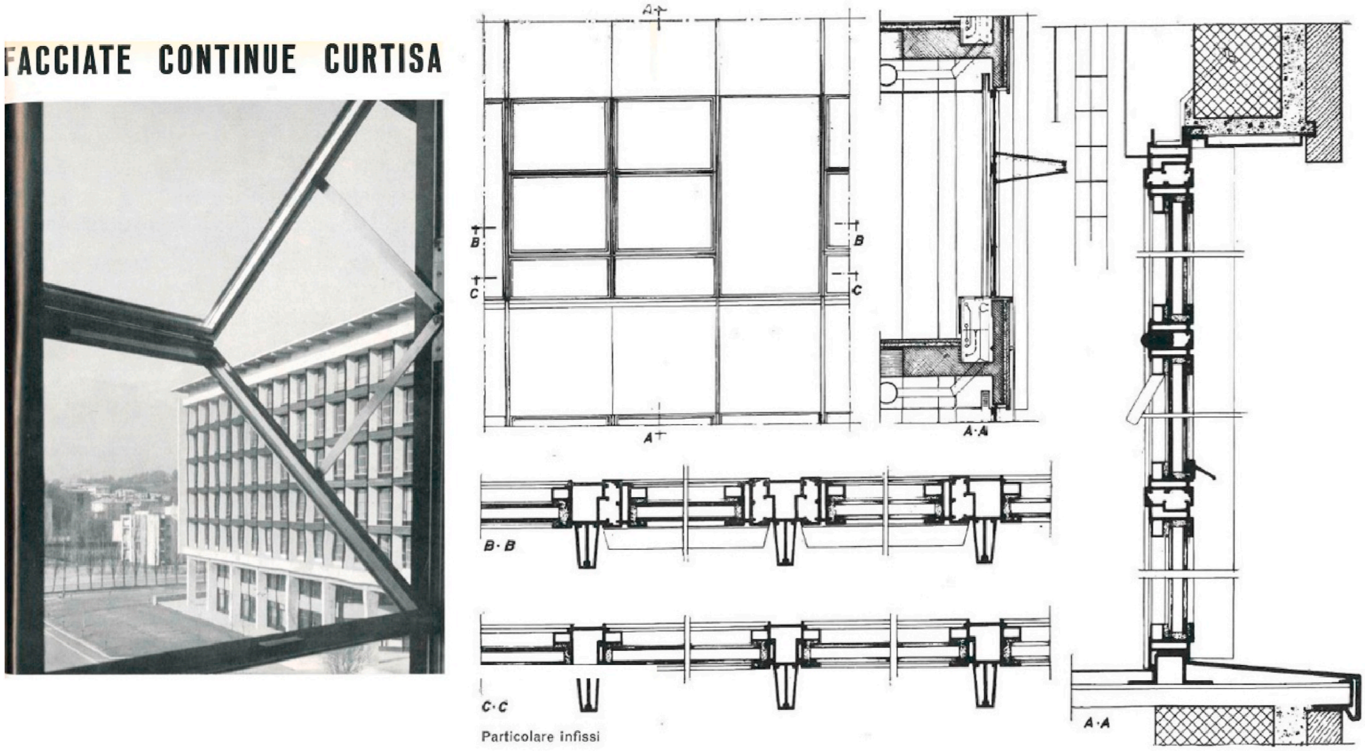


Fig. 4. The window book-opening system developed and patented by the Curtisa façade builder.

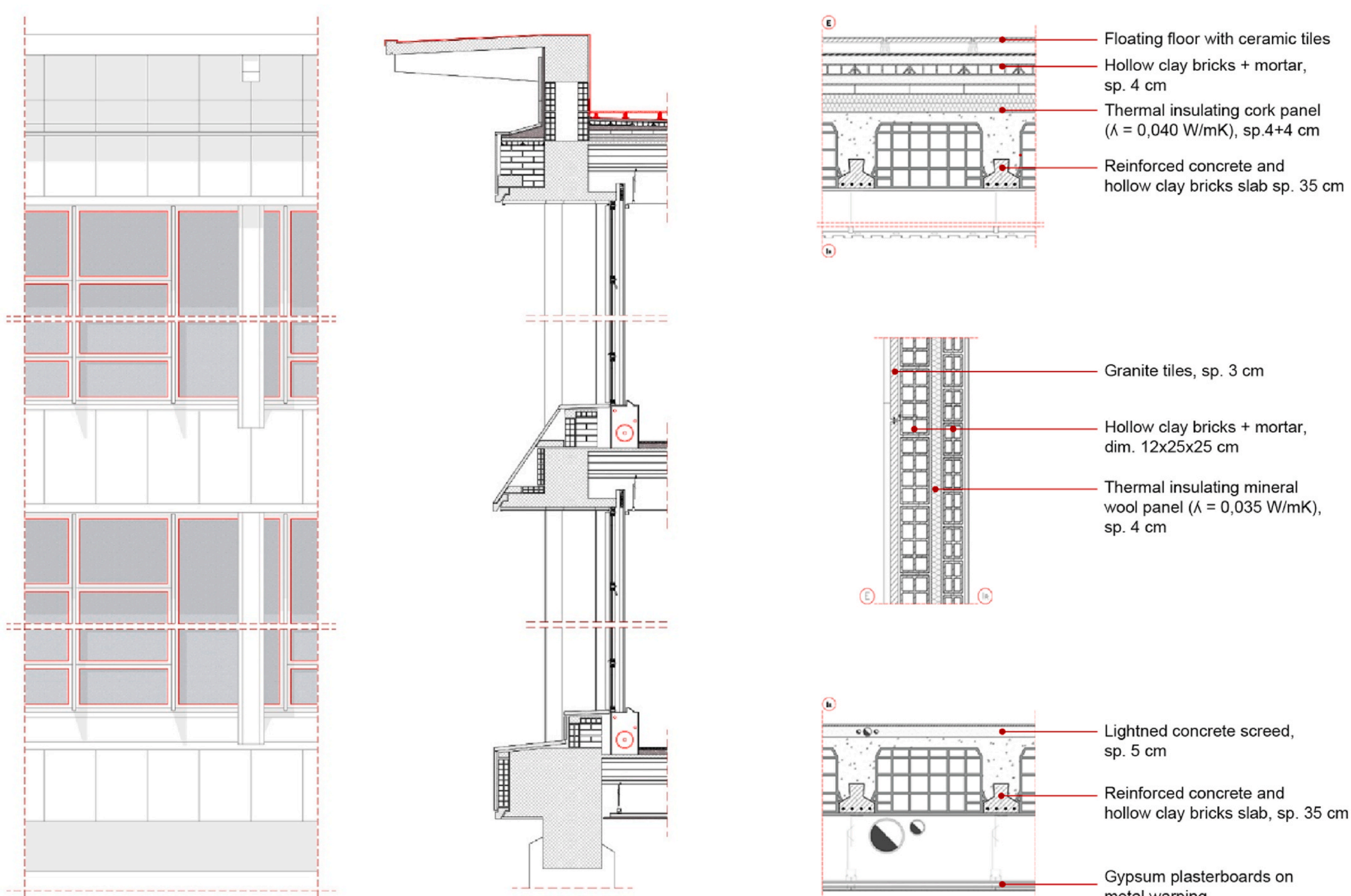


Fig. 5. Actual state survey: façade, section and building layers on the west side; drawings G. Galbiati, F. Medici.

2.5. Thermal diagnosis

The energetical analysis is carried on according to the Italian and European legislation [2,3,45], which imposes a series of threshold values, typically concerning the U′-values of both opaque and transparent elements. It is important to underline that performance requirements must be verified only for the portions interested by the retrofitting. Also, the respect of a global coefficient of heat exchange H'_T is demanded.

U’ values, i.e., the U value considering any thermal bridge are evaluated for all the different stratigraphy by applying Eq. (1), as shown in Table 2, after numerically evaluating the transmittance of each building element in Pan7.1 [46] and the effect of different linear thermal bridges in Iris4.1 [47], a finite element heat transmission simulator following UNI EN 10211 [48] standards.

Weather data for the simulations were obtained from the national Italian database, according to UNI 10349 [49,50].

$$U' = U + \frac{\Sigma\psi\cdot l}{A}\left[\frac{W}{m^2K}\right] \quad (1)$$

where U is the thermal transmittance of the building envelope element in W/m^2K, A the area of the building envelope element in m^2, and $\Sigma\psi\cdot l$ the sum of all products of thermal bridges in W/mK and l the length of thermal bridges. The ψ-values correspond to the internal dimensions of the thermal bridge cross-section, describing the influence of the thermal bridge on the total heat flow. For the Olivetti palace and considering the indications provided in UNI EN 14683 [51], the thermal bridges can be classified as linear and they are generated by the geometry of the building, such as the intersection of the external wall with the floors or the roof.

Another important tool, adopted in this study, is the thermal camera [52]. The analysis was done on the January 16, 2020 at 5.30 p.m., when the heating system was fully functioning. The weather was cloudy and the external temperature was +4 °C. All photos were taken at a distance of between 5 m and 10 m from the building’s façade. Thanks to this instrument it was possible to assess the absence of thermal insulation under the first floor, in correspondence with the porch, the discrete insulation of the vertical facades, and the high quantity of thermal losses caused by the original and unreplaceable aluminum frames, Fig. 6.

2.5.1. Building model for energy simulation

The energy performance of the case study was assessed through energy simulations in ProCasaClima11.1 [53].

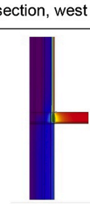
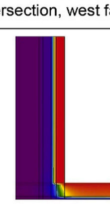
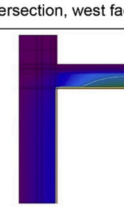
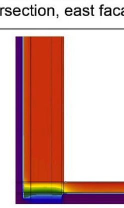
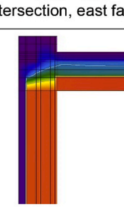
The first step was the definition of the geometry, dimensions, and position of the thermal envelope referring to the architectural and technological analysis.

Concerning the external climate conditions, the city of Ivrea is classified in the Italian Climatic Zone “E” [54], characterized by 2676 Heating Degree-Days (baseline 20 °C), resulting in a moderate climate, described by warm summers and fresh winters. Weather data were obtained from the national database, referring to UNI 10349 [49,50]. Summary information for the climate conditions of the site is reported in Table 3.

The annual energy demand for the space heating is evaluated per conditioned floor area (KWh/m^2), from the 15th of October to the 15th of April, considering 14 working hours per day, according to the Italian law for the corresponding climatic zone [55]. A set-point temperature of 20 °C, recommended by ISO 13790 [56] was selected. The cooling energy demand is, instead, considered negligible since it is verified that in

Table 2
Current state thermo-hygrometric performances and thermal bridges analysis. In red the current values that do not meet the standard values imposed by the legislation.

Building Element	Static transmittance (U) [W/m^2K]		Periodic transmittance (Y) [W/m^2K]		Condensation risk
	Current Value	Standard Value	Current Value	Standard Value	
Porch Slab	1,12	0,31	0.29	0.18	present
Roof	0,40	0,26	0.22	0.18	absent
Facade	1,31	0,30	0.42	0.10	present
Windows	3,50	1,90	-	-	present

Location of the thermal bridge	Wall – intermediate floor intersection, west facade	Wall – first floor Intersection, west facade	Wall – roof Intersection, west facade
IRIS simulation			
ψ (W/mK)	0.102	0.708	0.101
Location of the thermal bridge	Wall – intermediate floor intersection, east facade	Wall – first floor Intersection, east facade	Wall – roof Intersection, east facade
IRIS simulation			
ψ (W/mK)	1.603	2.400	0.704

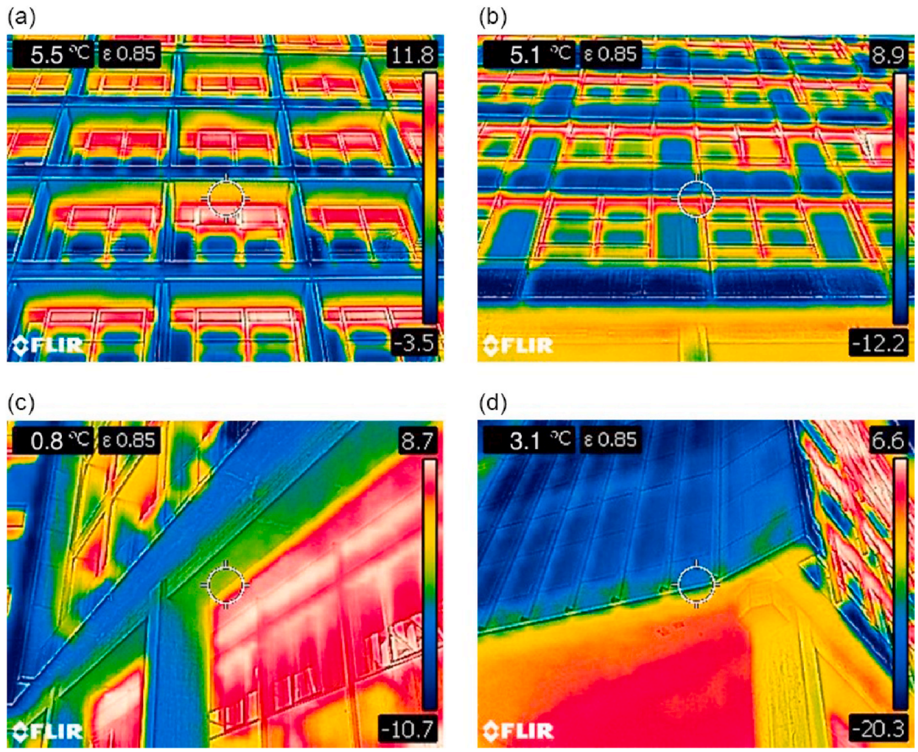


Fig. 6. Thermography results underline the relevant thermal losses through the original aluminum frames on the west façade (a), east façade (b) and in correspondence of the porch slab (c, d).

Table 3
Climate characteristics of the building site, Ivrea.

Italian Climate Zone	E
Annual mean Dry Bulb Temperature	12.6 °C
Maximum Dry Bulb Temperature	33.1 °C (Jul)
Minimum Dry Bulb Temperature	-8.0 °C (Jan)
Annual mean Relative Humidity	76%
Maximum Relative Humidity	93% (Nov)
Minimum relative Humidity	54% (Jul)

the summer season most of the offices are closed or only partially opened, Fig. 7.

The Heating Ventilation and Air Conditioning (HVAC) system considered for the simulations is composed of seven air handling units, six for the offices and one for the full-height central staircase. Both have a heat exchanger with an efficiency η of 0.85. The heated air introduced in the palace is evaluated considering the spaces volume and their occupancy, resulting respectively 18.500 m^3/h and 30.200 m^3/h, to heat a volume of 12.000 m^3 and 7.100 m^3. These are effectively the real operational values, as confirmed by the building's technicians. Other technical data for the HVAC system came from the construction and operational manual [57].

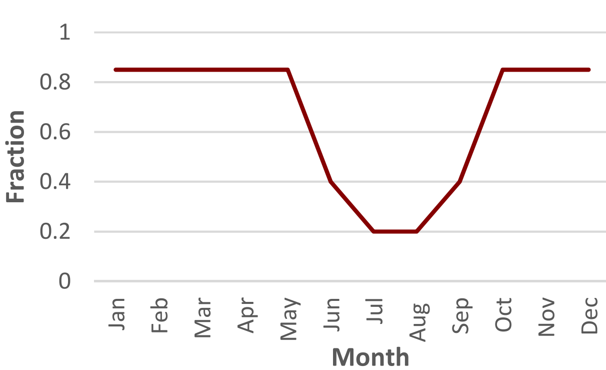


Fig. 7. Monthly occupancy schedule.

According to ISO 13790, the building was divided into thermal zones. For the Olivetti office building, a unique thermal zone is considered for all the heated offices, since the internal temperature can be regarded the same. The attic, utility rooms, and the basement are considered to be unconditioned, as summed up in Table 4.

Internal heat gains generated by the occupants are considered by assuming an average activity level of 140 W/person [58] and an occupancy level of 30 m^2/person, according to the real use. The heat flow, considering some underused areas, results approximately in 3 W/m^2. The occupants' heat gains are based on a typical occupancy time schedule for an office [59]. The heat gains from interior lighting are evaluated on a watts/area calculation method basis. The lighting level is estimated to be approximately 10 W/m^2, and the lighting schedule is based on the occupancy one, considering that the office is empty early in the morning and after 6 p.m., Fig. 8. Also, the presence of electronic devices, like computers or printers, is considered, with an impact of 12 W/m^2. The heat gains generated from hot water circulation pipes in the bathrooms are considered negligible. All the simulation parameters are summarized in Table 5.

Thermal bridges and air infiltrations (air leakages) also need to be considered. The natural ventilation and infiltration losses are calculated considering the design flow rate calculation method based on the number of air changes per hour (ACH), according to ISO 13790.

Table 4
Thermal zone definition.

Thermal zone	m^3	Level	Space
Offices	72000	1–7	Heated
Distribution/stair	7500	1–7	Heated
Underground	10800	-1	Not-heated
Attic	1250	7	Not-heated

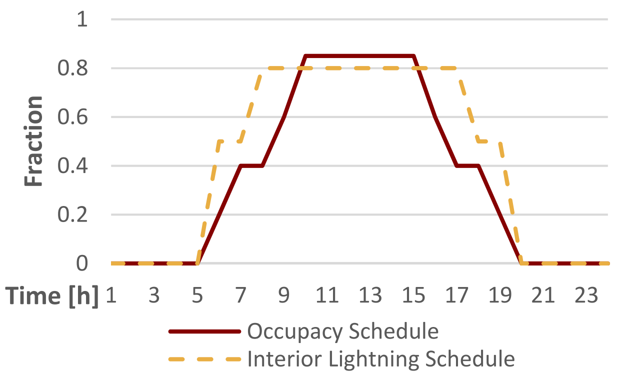


Fig. 8. Occupancy and lighting hourly schedule.

Table 5
Main parameters of the energy simulations.

Simulation parameters	Value	Unit
Air infiltration rate	0.7 h^{-1}	ACH
Heating set-point	20	°C
Occupants heat gain	3	W/m^2
Artificial lighting load	10	W/m^2
Electric equipment heat gains	12	W/m^2

Moreover, the ageing of the materials is considered by increasing the conventional thermal conductivity of the building elements [60], such in the case, for example, of the exterior wall thermal insulation in rock wool panels. To account for thermal bridging in the building energy simulation, the U′-value, i.e., the thermal transmittance of envelope elements including the thermal bridges Fig. 9 is calculated according to Eq. (1).

Finally, the energy demand for space heating in the actual state results to be 81 KWh/m^{2}y. This value, particularly low if compared with contemporary realization, is considered reliable and found very close to the actual energy demand indicated by the owner (76 KWh/m^{2}y).

Considering the heat losses through the façade, they are mainly localized in correspondence of the windows (62%), in particular through the original frames, and in the uninsulated porch slab (26%). The high losses level and the impossibility of any frame replacement represent the true challenge for the following redesign. Finally, yearly thermal loads cover more than 70% of total thermal losses: the objective is to strongly reduce them.

To define a target, the energy demand for space heating for a reference building has been calculated. This building, according to the Italian legislation DM June 26, 2015 [45], is an ideal building, identical to the case study in terms of geometry, orientation, location, intended use, surroundings but with thermal and energetical characteristics imposed by the norm. Considering the 2015–2021 standards a target value of 36 KWh/m^{2}y was found while considering the after 2021 standards the value is 29 KWh/m^{2}y.

2.6. *Variants proposition*

Four different retrofitting variants, designed in a 1.20 scale, are proposed to optimize the building's envelope as shown in Fig. 10. Particular attention is given to the porch slab, the typical intersection between the wall and the floor, and the roof corner. All the new parts are represented in red in the drawings.

The common base for the different propositions is the internal insulation, with each time more invasive solutions. The reconstruction of a new and identical façade is not considered in this study for multiple reasons: the low level of sustainability, the high intervention costs, and the legal restriction imposed by DL 42/2004 [22]. Taking into consideration the cost/benefits and the technical feasibility, the choice is to prefer traditional materials, as rook wool, for insulation. Large use of high-performance materials for vacuum or heat-reflecting insulation is

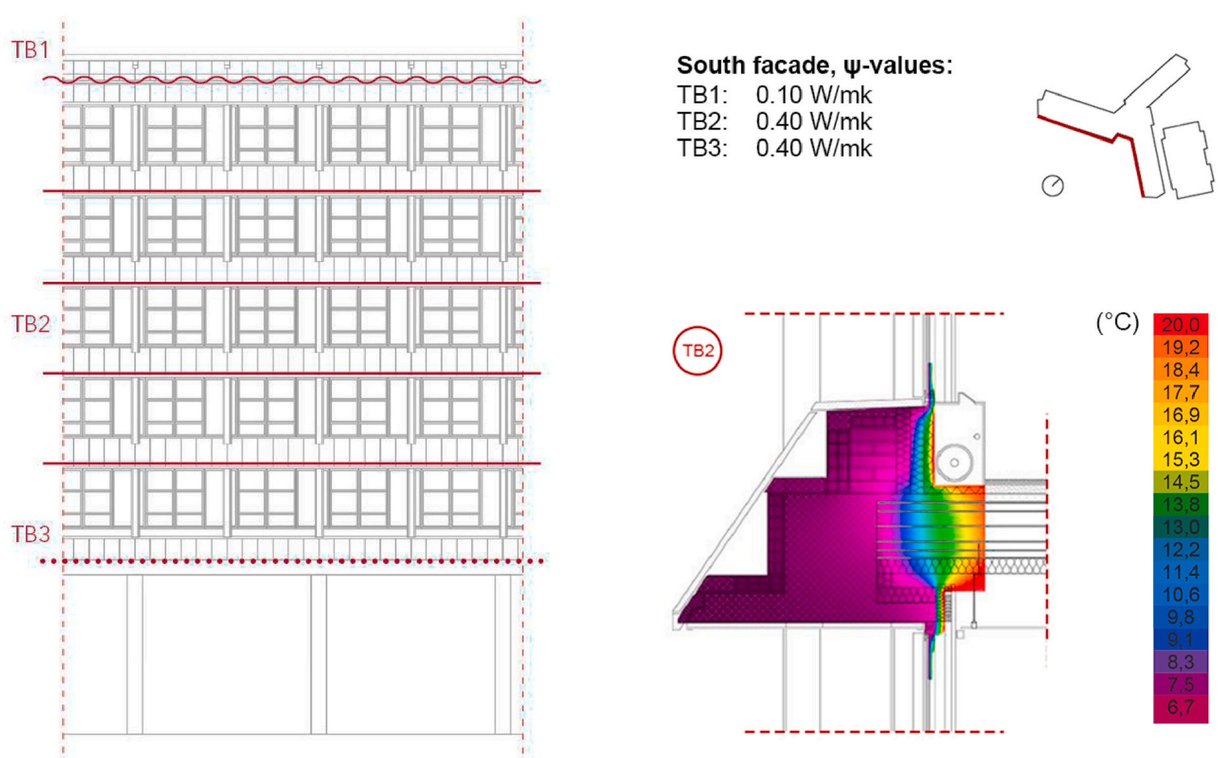


Fig. 9. Localization of the main thermal bridges, evaluation of their correspondent ψ-values, and an example of finite element analysis for the typical South Façade, TB2 case. The same process is applied to all the building façades.

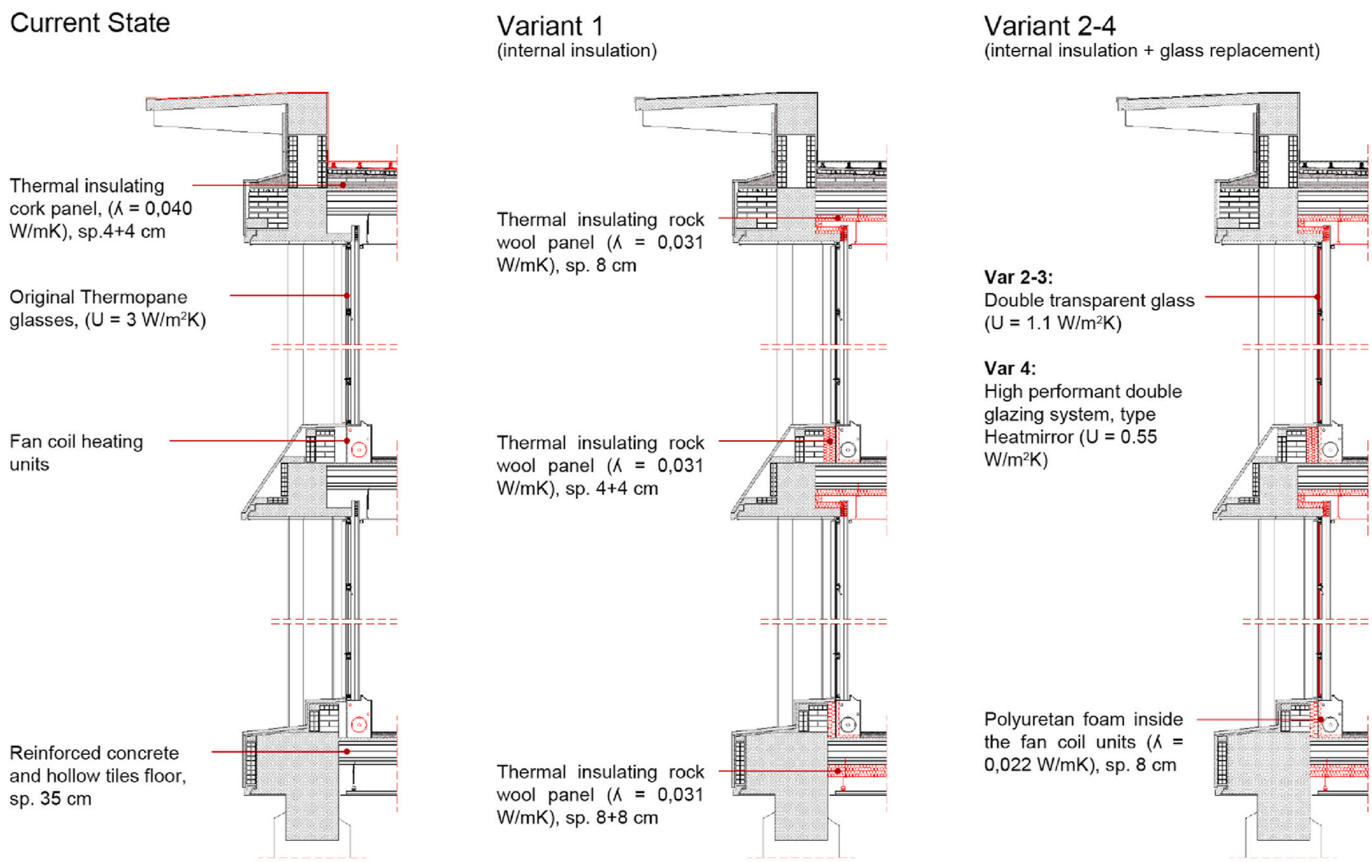


Fig. 10. Main interventions for the west façade compared to the current state; drawing G. Galbiati, F. Medici.

considered not appropriate and not necessary. As regards only the windows, high-performance glasses were adopted in the 4th variant, since research exploiting the benefits of glass coatings indicates energy savings between 7% and 25% [61,62]. The variants are synthetically reported in Table 6.

2.6.1. *Variant 1 - internal insulation*

The first variant consists of the addition of internal thermal insulation in correspondence with the hidden façade parts, the porch slab, and the roof. This strategy is used as the starting point for the definition of the other three design variants.

In this case, 16 cm of rock wool (λ = 0.031 W/mK) are placed under the porch slab, into the existing false ceiling. Under the ground-floor's slab, in correspondence with the underground unconditioned spaces, the addition of 12 cm of rock wool is proposed, while on the roof, thanks to its good original design, only 8 cm of thermal insulation are necessary. This fact is justified by the presence of 8 cm of original cork panels for thermal and acoustic insulation. Regarding the facades, 12 cm of rock wool are used to insulate the opaque parts. In addition to these, 4 cm of polyurethane foam in closed-cell Polyso PIR (λ = 0.022 W/mK) are located inside the fan coil units. Rock wool panels are posed into the accessible cavities, giving continuity to the insulation layer. Other 8 cm of wood wool panels (λ = 0.031 W/mK) for a length of 1.5 m are placed under each internal floor, starting from the external wall and hidden in the false ceiling, to reduce the effect of the existing thermal bridge.

The energy demand for space heating is 54 KWh/m^{2}y, with an Energy Demand Reduction (EDR) of -33%, if compared to the actual state. To improve the energy efficiency of the building, the next variants will be concentrated on windows optimization [63,64]. It effectively brings significant EDR in buildings with a large window to wall ratio [65], as in the case of the Olivetti palace.

Table 6
Summary of the interventions associated with each variant. In Variant 4 the glass replacement is intended with high-performance glasses, type HeatMirror (*).

	INSULATION			REPLACEMENT	
	PORCH SLAB	FACADE	ROOF	TRANSPARENT GLASS	BRONZE GLASS
VAR. 1	●	●	●		
VAR. 2	●	●	●	●	
VAR. 3	●	●	●	●	●
VAR. 4	●	●	●	●*	●*

2.6.2. *Variant 2 - internal insulation and partial glass replacement*

The second variant is based on the insulation solutions provided in the first one. In addition to this, the replacement of the original transparent Thermopane glasses, on the east and south facades of the building, (U-value 3.0 W/m^{2}K) with a more efficient double transparent glass (U-value 1.1 W/m^{2}K) is proposed. The bronze reflecting glasses on the west facade are maintained since they are considered distinctive elements with historical value. Furthermore, from an energetic and economic point of view, they respond well to the internal comfort needs and their replacement would imply a considerable cost increase.

Variant 2 allows a sensible thermal needs reduction. The energy demand for space heating is 36 KWh/m^{2}y, with an EDR of -55%, if compared to the actual status, and -33%, if compared to variant 1. This retrofitting solution represents a very good intervention strategy, respecting the standards imposed by the 2015–2021 Italian legislation. But imagining that the project will be done in the future, with more restrictive energetical thresholds, the interest of evaluating better solutions remains.

2.6.3. Variant 3 - internal insulation and total glass replacement

The third variant is intended as an implementation of the previous one. In order to investigate the optimization possibility of the building envelope, all the glasses are now replaced with the double transparent glass of Variant 2 (U-value 1.1 W/m^{2}K). This choice will help to understand the energetical impact of the bronze reflecting glasses on the global thermal needs of the palace.

In these last two variants, the possibility to replace the existent glasses with high-performing triple glazing is discarded. The higher dimensions of the elements and the increase in weight would have made impossible their installation and the handling of the original opening system.

The energy demand for space heating is 32 KWh/m^{2}y, with an EDR of -61%, if compared to the actual status, and -11% if compared to variant 2. As can be seen, the replacement of the bronze glasses has not a relevant effect on the energetical optimization of the building. Furthermore, a sensible increase in retrofitting costs needs to be considered.

2.6.4. Variant 4 - internal insulation and total glass replacement (high-performance glass)

The fourth and last variant has the objective to study the best retrofitting solution from an energetical point of view. The aim is to reach the standard values according to the after 2021 legislation (Energy demand of 29 KWh/m^{2}y).

In this variant, the total replacement of the windows' glasses with a high-performance double glazing system type HeatMirror passive (U-value 0.55 W/m^{2}K) is proposed. This glass, with the weight and dimension of a typical double-glazing system, allows reaching very high energetical performances. But on the other hand, a negative aspect is due to the aesthetic, appearing excessively reflecting, even if adopted in its neutral shade.

The energy demand for space heating is 27 KWh/m^{2}y, with an EDR of -68%, if compared to the actual status, and -16% if compared to Variant 3.

The fourth retrofitting solution is the only one capable of reaching optimal energetical standards, even better than demanded, but at the expense of the architectural aspect of the building.

2.7. The multi-criteria comparison

In the graphical anlysis, the four variants are firstly compared in terms of yearly thermal losses and gains, considering for each case the corresponding improvement, Fig. 11. The impact of glass replacement is independently analyzed for each variant. This allows assessing that new and performant glasses are fundamental elements to reach energy efficiency. It is demonstrated that the replacement of the bronze reflecting glasses on the west facade doesn't play a decisive role. Only the adoption of the HeatMirror glasses strongly reduces the thermal losses. Finally, the values of energy demand and heat losses are separately evaluated for each variant. They are not only compared the one with the others but always with the current state and the two regulation standards [45]. Fig. 12.

Starting from these considerations, the estimation matrix is elaborated. It presents on the lines the four project variants and in the columns the evaluation criteria. Among them: energy demand, architectural quality, heritage respect, technical and economic feasibility. The fundamental aspect of this approach is the possibility to consider in a single evaluation process, both the quantitative (energy demands, costs, technical feasibility) and qualitative (architectural quality and heritage respect) aspects. The values of the quantitative criteria come from the previous analysis: the energy demand is expressed in KWh/m^{2}y, while technical and economic feasibility are evaluated with a score between 1 (very bad solution) to 10 (very good solution) according to the time of realization and technical complexity or depending on the owner's budget. Also, the qualitative criteria are evaluated with a score between 1 and 10. In this case, it deals with a critical operation, which asks a deep knowledge about architectural restoration theories and shared deontology. The scores are assigned according to the commonly shared principles in the field, based on the Venice Charter [66] and the Nara Document [67]. International standards in heritage conservation, coming from UNESCO [68], as well as national guidelines from the MiBACT (Italian Ministry of Culture) [69], are considered. They outline the key principles for the score assignment: compatibility (chemical and physical), reversibility, and minimum intervention [70,71]. The benefits of using a decision-making matrix in architectural retrofits have been demonstrated and validated by numerous research [24,72–74]. Table 7 shows the evaluation matrix. Since quantitative and qualitative values are not directly comparable with each other, the matrix is normalized using Eq. (2) for each evaluation criterion. The normalized matrix is given in Table 8.

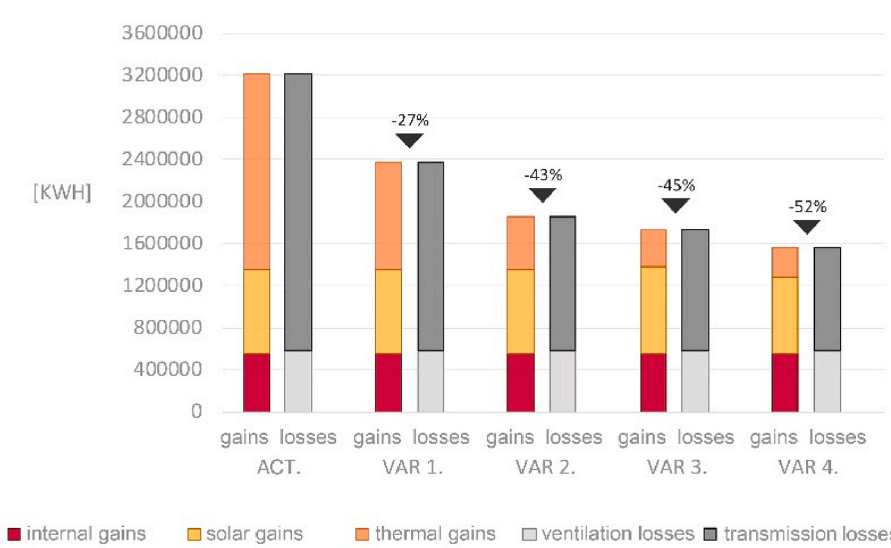


Fig. 11. Energy demand for space heating. Thermal gains vs. thermal losses for each variant and the actual state.

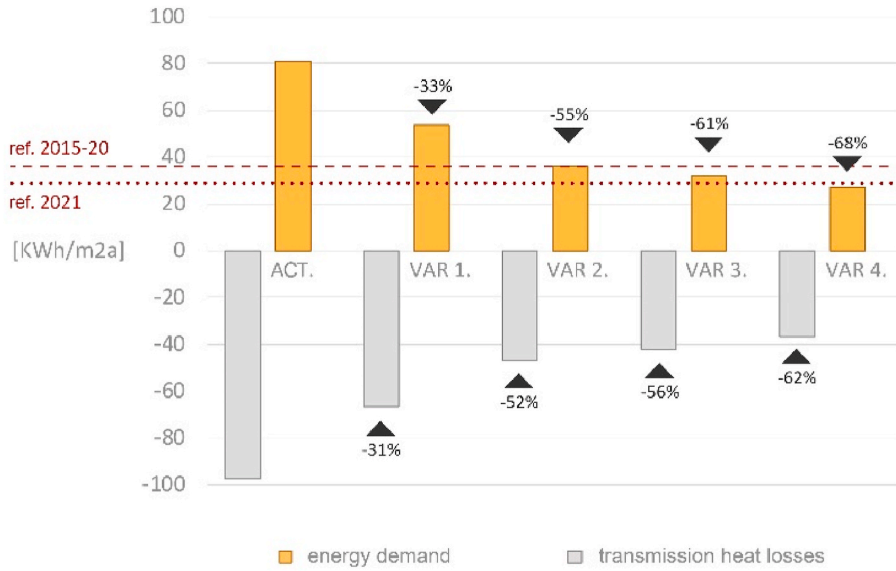


Fig. 12. Energy demand vs. transmission heat losses for each variant. Values compared with the actual and future standards.

Table 7
Evaluation matrix for the multi-criteria comparison. The values are dependent on the unit of measure and not comparable the one with the other.

	Energy Demand [KWh/m2y]	Architectural Quality	Heritage Respect	Technical Feasibility	Economic Feasibility
VAR 1	54	10	10	10	10
VAR 2	36	10	9	9	9
VAR 3	32	8	8	9	8
VAR 4	27	5	8	9	6

Table 8
Normalized evaluation matrix. The values are not dependent on the unit of measure.

	Energy Demand	Architectural Quality	Heritage Respect	Technical Feasibility	Economic Feasibility
VAR 1	0.64	0.30	0.32	0.27	0.30
VAR 2	0.76	0.30	0.29	0.24	0.27
VAR 3	0.78	0.24	0.26	0.24	0.24
VAR 4	0.82	0.15	0.26	0.24	0.18

$$normalized\ value = \frac{value}{\sum values} \tag{2}$$

Finally, since the five criteria represent different project priorities, the normalized matrix is multiplicated for a priority vector. In the AHP approach, the vector $\underline{v}$ expresses the average importance given to each criterion coming from regulatory dispositions, best practices, worksite technical feasibility and stakeholders' needs. A value higher or lower than unity gives the criterion higher or lower importance. In this case, the resultant vector is: $\underline{v} = (1.4, 1.1, 1.3, 1.0, 0.8)$. It is again a qualitative operation since the priority vector has the peculiarity to change according to each specific project need [24]. The final evaluation matrix given by the product of the priority vector for the normalized matrix is shown in Table 9. It presents the variant that reaches the highest total score.

3. Results: the most suitable retrofitting solution

The application of the MERMA shows that the optimal project solution consists in Variant 2. Fig. 13.

The building, even if protected by the historical monuments law, meets all the standards imposed by the legislation [45], avoiding any possible derogation. A value of $H'_T = 0.61$ W/m^{2}K respects the threshold of the global coefficient of heat exchange ($H'_T = 0.65$ W/m^{2}K).

All the U-values [W/m^{2}K] for the building layers, opaque and transparent elements, are respected as shown in Table 10. For the windows, the value of g_{gl+sh} between 0.29 and 0.33 meets the regulatory limit of 0.35. Any risk of condensation or presence of mold is excluded, by simulations done with Pan7.1. Attention is given, also, to the definition of other parameters not always specified by the norms, among these: the periodic transmittance, thermal displacement, and thermal attenuation. Concerning these aspects, a thermal displacement higher than 10 h is always assured.

But if the retrofitting will be done after 2021, Variant 2 will no longer respect all the more restrictive standards imposed by the norms. Only in this case, we can admit a minimal derogation, possible according to the historical monuments law DL.42/2004. This attitude is perfectly aligned with the management plan previewed by UNESCO.

4. Discussion and conclusion

The MERMA application ensures for the Olivetti palace about 55% of energy savings while conserving the character-defining elements of the building. From the meticulous knowledge of the existing situation and the redesign of the technical details, the most appropriate solution emerges. The intervention is mainly focused on the building façades, providing first of all an internal and hidden insulation, eliminating the thermal bridges or limiting them where technical infeasibilities are found, as in the case of the typical floor slab. This first intervention allows about 33% of energy savings, which is in line with the typical range between 25% and 47% [3,75,76]. Secondly, the glass replacement plays a key role in EDR without impacting on the external aesthetics of the building. Also, the frames' replacement would ensure better performances [77], but the legal restrictions about it push this study to look for alternative solutions. The final objective to meet all the standards

Table 9
Final step matrix analysis. In green the variant (VAR 2) with the highest total score.

	Energy Demand	Architectural Quality	Heritage Respect	Technical Feasibility	Economic Feasibility	Total Score
VAR 1	0,89	0,33	0,41	0,27	0,24	2,14
VAR 2	1,06	0,33	0,38	.0,24	0,22	2,23
VAR 3	1,09	0,26	0,34	0,24	0,19	2,12
VAR 4	1,15	0,17	0,34	0,24	0,14	2,04

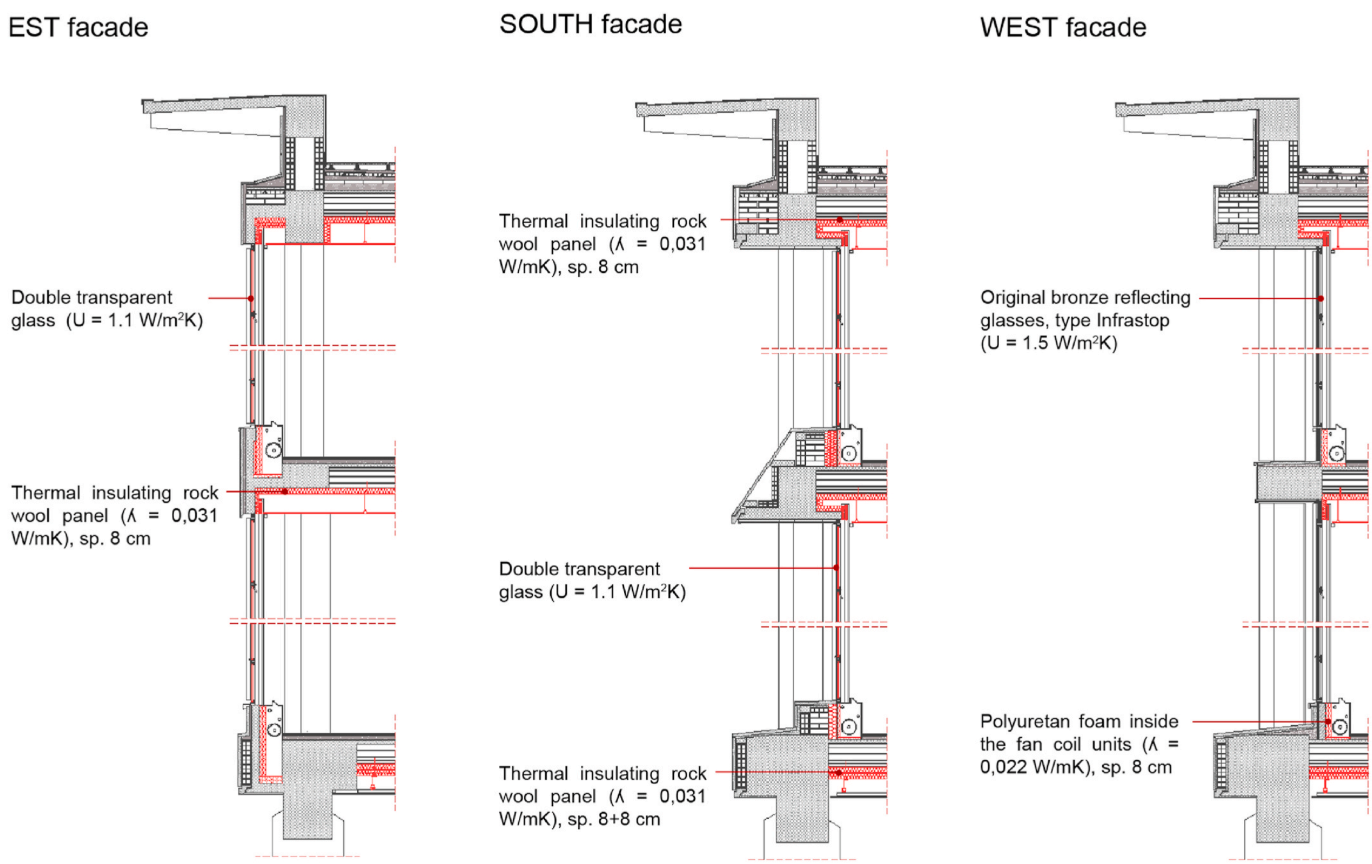


Fig. 13. Variant 2, retrofitting solution for the three facade orientations; drawing G. Galbiati, F. Medici.

Table 10
Thermo-hygrometric performances improvement for Variant 2. In green: all the standard values imposed by the Italian legislation are respected.

Building Element	Static transmittance (U) [W/m²K]			Periodic transmittance (Y) [W/m²K]			Thermal phase Shift	Condensation risk
	Variant 2	Standard Value	Improvement	Variant 2	Standard Value	Improvement		
Porch Slab	0,17	0,31	85 %	0.010	0.18	95 %	11h 0'	absent
Roof	0,20	0,26	50 %	0.010	0.18	95 %	14h 4'	absent
Facade	0,24	0,30	80 %	0.039	0.10	90 %	10h 51'	absent
Windows	1,80	1,90	49 %	-	-	-	-	absent

required by the norms has been achieved, even admitting the presence of the historical aluminium frames. Since this study is mainly based on numerical estimations, further development will include mock-up realization and *in-situ* simulations. Also, the possibility of future occupancy changes after refurbishment, implying a general increase in cooling demand is going to be considered.

Effectively, the MERMA does not aim to drastically change the existing building to construct a net-zero energy/carbon one, but to find the right balance between heritage preservation and energy improvement, as the two are mostly complementary to each other. The AHP matrix approach permits the complex evaluation of both qualitative and quantitative criteria to find the best alternative. The final result is not the scenario that optimizes each criterion, but the one that reaches the best compromise, respecting at the same time all the other criteria [24]. In this sense, the MERMA, thanks to its multi-disciplinarity and inclusive method, can be regarded as the first methodological tool capable of considering conservation principles for Modern Architecture, promoting the adoption of minimal intervention, looking at the stakeholders' needs, and being sustainable from an environmental point of view.

In terms of procedure, but also terms of results, the methodology is a valuable precedent, extendable by analogy to a broader corpus of similar objects. Effectively, starting from the application of a general methodological framework, the use of the priority vector allows to balance the project needs according to the specific requirements of each building, providing a pragmatic response to the unavoidable challenges of saving resources. Further research for this study will include comparing retrofit carbon emissions to carbon savings due to energy reduction as well as the integration of renewables. Moreover, due to the above-mentioned complexity and the specificity of the preservation field, the MERMA has been developed for Modern Architecture with curtain walls or light façades, which represent the most popular technology in the second half of the 20th century. The next step will be the methodology test on other building types with different features, for instance for heavy prefabricated systems and, finally, to more routine examples of the II postwar building stock. Furthermore, the MERMA will be also applied in areas with different climate conditions, especially where the Cooling Degree Days value is high and façade insulation is less efficient [78,79]. This wider-scale approach of increasing the number of building types subject to retrofit would enhance the achievement of ambitious energy-efficiency targets and would significantly improve the living conditions of the users. In this way, the research is conceived as a pilot study, providing a cohesive general methodology for future retrofitting of Modern Architecture, demonstrating how this issue can play a key role in sustainable development. Swiss Confederation's words are explicit in this sense: heritage and energetic issues are both legitimate, they refer fundamentally to the same preoccupation and aim to the same goals: to promote sustainable development. It deals with the preservation of irreplaceable resources, natural or cultural as they are [80].

CRediT authorship contribution statement

Giuseppe Galbiati: writing, methodology, original draft, main investigation, editing. **Fortunato Medici:** numerical implementation, investigation, computation, drawings, editing. **Franz Graf:** conceptualization, supervision, methodology, review, investigation. **Giulia Marino:** conceptualization, supervision, methodology, investigation, formal analysis, review.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationship that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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