Journal of Sustainable Development of Energy, Water and Environment Systems

http://www.sdewes.org/jsdewes

Year 2020, Volume 8, Issue 4, pp 715-734

Preliminary Energy Evaluations for the Retrofit of Rural Protected Buildings in a Peripheral Context of Milan

Paola Caputo[*1], *Simone Ferrari*[2], *Giulio Ferla*[3], *Federica Zagarella*[4]

[1]Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Via Giuseppe Ponzio, 31, Milano, Italy
e-mail: paola.caputo@polimi.it

[2]Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Via Giuseppe Ponzio, 31, Milano, Italy
e-mail: simone.ferrari@polimi.it

[3]Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Via Giuseppe Ponzio, 31, Milano, Italy
e-mail: giulio.ferla@polimi.it

[4]Department of Architecture, Built Environment and Construction Engineering, Politecnico di Milano, Via Giuseppe Ponzio, 31, Milano, Italy
e-mail: federica.zagarella@polimi.it

Cite as: Caputo, P., Ferrari, S., Ferla, G., Zagarella, F., Preliminary Energy Evaluations for the Retrofit of Rural Protected Buildings in a Peripheral Context of Milan, J. sustain. dev. energy water environ. syst., 8(4), pp 715-734, 2020, DOI: https://doi.org/10.13044/j.sdewes.d8.0332

ABSTRACT

This research is framed in the development of an agri-food hub in the city of Milan, including retrofitting an historical farmhouse. In particular, it focuses on the renovation of two historical buildings within the farmhouse. It aims to present a method to support the energy retrofit design of protected buildings, assuming the possibility of achieving high energy efficiency and integration of local renewable sources, while respecting the constraints related to the building's historical value. Two envelope scenarios, with internal and external insulation, were developed, simulated with Integrated Environmental Solutions: Virtual Environment tool and evaluated. As main results, for the demand side there are no significant differences in terms of energy loads on yearly basis in the two retrofit scenarios, on the supply side, several aspects were considered, including the local renewable potential. Concluding, the application of the described method to the mentioned case study can support in tackling the challenges of protected buildings energy retrofit.

KEYWORDS

Historical rural building retrofit, Buildings protection constraints, Cultural heritage, Dynamic simulations, Buildings renewables integration, Profiles definition for the internal loads.

INTRODUCTION

The global challenge toward the reduction of CO_2 emissions and the related mitigation of climate change phenomena identifies a fundamental role in the upgrading of the energy efficiency in the building sector. Indeed, in Europe buildings are

[*] Corresponding author

responsible of consuming 41% of the total final energy demand [1]. Among the built environment, existing residential buildings offer the highest energy saving potential: more than the 40% of European stock have been constructed before the 1960s when regulations about energy uses in buildings were very limited [1], and even by means of small interventions at the envelope level, great results in terms of energy performance can be achieved. Moreover, focusing on Italy, even if a large portion of the building stock has been realized between the '50s and the '80s, more than 3,900,000 buildings have been built before 1920, and several of them are characterized by historic and artistic value [2]. Nevertheless, all the national buildings built over seventy years ago, although not always characterized by a monumental importance in them, are amenable to protection: these buildings determine the national architectural building heritage, the historical identity of unique urban contexts [3]. The application of the energy efficiency upgrade of buildings identified as 'cultural good' is a sensitive issue, especially in Italy, and considering its wide variety, age by age, it is not possible to have a unique approach to the problem that is possible for new constructions [4]. Therefore, each intervention must be combined with a deep acknowledgment of the project context and a feasibility evaluation. The European directive in matters of energy efficiency, Directive 2010/31/EU [5], the so-called EPBD Recast, and the relative Italian implementation [6], do not give particular indications for heritage. For this reason, in Italy, through the Law 90/13 [7] some categories of buildings, including protected ones, can be excluded from the achievement of minimum energy requirements after the application of energy retrofit actions. In order to approach a renovation on a protected building, the design phase must focus on the research of the best compromise between advanced and sustainable technologies, to guarantee thermal comfort, good energy performance and conservation of the traditional elements of the buildings [8].

The pursuit of this delicate balance has to be combined with a continuous dialogue with the Superintendence that evaluates case by case the compliance of the intervention planned with the conservation of the historical and/or artistic value of the construction. The retrofit activity on old buildings in Italy seems a very difficult challenge, considering the matching among regulations, technical, energy and economic feasibilities [9]. The need of clear references and tools to face the issue has been stressed by many researches in order to support designers and customers and to avoid the derogation regime [10] to which protected buildings, most of the time, undergo.

In a recent review study [11], typical energy retrofit measures have been discussed by the difficulty level of application, leading to the finding that the most critical one is the improvement of the envelope insulation due to limits of intervention on protected façades. Also, among the surveyed articles the most common envelope related intervention was the thermal plaster, while few studies considered the insulation of walls from inside and even less, from outside. Several studies have investigated the influence of both thickness and position of insulation in walls on building thermal performance, highlighting the better performance of insulation from outside. For instance, this has been studied based on the hygrothermal behaviour of the walls in Cho *et al*. [12], analysing the inertia effects in case of buildings conditioned by earth-air heat exchanger in Rosti *et al*. [13] or in case of bedrooms with intermittent air-conditioning in Cheng *et al*. [14]. However, the choice of insulation of the inner surface can sometimes be necessary, as in case of old buildings [15]. In this regard, even if the internal insulation allows appreciating good energy saving, it may incur a number of potential risks to the durability of the building fabric, due to interstitial condensation [16]. Hence, to prevent condensation in case of internal insulation, the possible installation of a vapor barrier on the warm side of it has to be evaluated, as discussed in Ferrari and Riva [17]. In the Kovacic *et al*. [18], after a comparison of several energy retrofit scenarios on a building block, the authors have pointed out that the installation of internal insulation is one of the best solutions from an overall energy, environmental and economic perspective, also is more compatible with protection criteria, although it reduces the useful floor area and is complex without tenants resettlement. Conversely, Roberti *et al*. [19], who presented a multi-criteria method for selecting the optimal energy retrofit scenario, pointed out that a partial insulation (i.e., concerning only surfaces without historic value) from inside is worse in terms of energy demand and comfort. In Ferrari and Romeo [3], in defining the building envelope measures, the insulation of the walls was provided only from inside surfaces, due to protection requirements, while the insulation of ground floor was allowed. Differently, in Ciulla *et al*. [20] the insulation of ground floor in historical buildings has not been considered in order to maintain its old features. In Gourlis and Kovacic [21], the authors assessed the energy renovation of an old industry, highlighting the relevant role of roof renovation in this type of buildings. In Salem *et al*. [22], the replacement of existing double-glazed windows with triple-glazed ones has been suggested. Conversely, in Ferrari and Romeo [3], the installation of internal double-glazed windows in addition to the existing single-glazed ones of the protected façade equipped was defined.

As highlighted in Alev *et al*. [23], a combination of different measures to be added to the envelope measures is necessary to achieve more ambitious targets.

Under the Heating, Ventilation and Air Conditioning (HVAC) systems point of view, many studies have investigated different solutions. For instance, in Becchio *et al*. [24] different alternatives of refurbishment were evaluated considering architectural heritage, energy efficiency and costs (low/high investment). A condensing boiler for space heating and a multi-split system for space cooling were assessed in the low investment scenario, which foresees a residential use, while a water-to-water Heat Pump (HP) and mechanical ventilation system in the high investment scenario, which foresees a touristic use. In Ferrari and Romeo [3], in order to meet the thermal energy systems and renewable sources requirements as well as practice to assess a likely replicable solution, an air-to-water HP was foreseen, although, as an alternative, the connection to district heating was also investigated. Both air-to-water and ground source HPs were assessed in Alev *et al*. [23]. To replace the existing condensing boiler, the installation of an air-to-water HP and the connection to district heating were alternatively assessed in Buso *et al*. [25]. Split systems for space cooling were foreseen in Congedo *et al*. [26]. Menconi *et al*. [27], by simulating several renovation scenarios involving different heat recovery ratio and energy sources for mechanical ventilation, highlighted the strong impact of the building service systems retrofit in historical buildings, mainly due to the low efficiencies of the replaced old systems. Micro-cogeneration was found as essential to achieve the desired energy performance in Salem *et al*. [22]. Blázquez *et al*. [28], by simulating and comparing different ventilation system scenarios for assessing the impact on both energy performance and thermal comfort, underline the importance of heat recovery coupled to mechanical ventilation to avoid consistent energy losses due to air changes. Conversely to the others studies, in Ciulla *et al*. [20], the integration of renewable energy technologies (such as geothermal energy or connection to district heating) was addressed as not always easy or feasible in historical buildings retrofit, however, some smart solutions at operational level (thermostats, controls, set-point temperature, etc.) are adoptable.

Solar systems integration can be complex in historical buildings also due to urban visual impact in cultural heritage contexts. In Ferrari and Romeo [3], the issue has been dealt by integrating Photovoltaic (PV) panels on the building roof pitch facing the internal courtyard. In Cellura *et al*. [2], the installation of PV panels was not allowed on the rural office building roof due to the surrounding archaeological area, and therefore was proposed on the car parking area. In Alev *et al*. [23], the installation of solar thermal systems for Domestic Hot Water (DHW) has been adopted. In Becchio *et al*. [24], both PV and solar thermal systems were adopted.

From Table 1, which summarizes the features of the selected studies from literature, the predominance of non-invasive measures on the external walls (i.e., thermal plaster or insulating panels from the inner side) and the installation of new windows can be noted. In some cases, the renovation also regarded roof and ground floor. In a few cases, HVAC and solar systems have also been considered.

Another relevant issue when accomplishing an energy retrofit of buildings is the choice of the method for evaluating the related energy performance. According to Webb [16], it can be done based on field measurements [29] or laboratory testing of the envelope thermal properties [30] or based on building energy simulation [9]. Considering the mentioned need of searching the optimal balance between protection constraints and energy saving requirements, building energy simulation can be a valuable method for comparing in advance several retrofit scenarios. A proper reliability of the results can be obtained adopting a detailed simulation tool, i.e., dynamic calculation-based, allowing to carefully define the building simulation model assumptions for the assessment of the building thermal energy needs [31].

The outlined framework highlights the open issues when designing suitable energy renovation measures accurately tailored on buildings.

This paper aims at the evaluation of the energy retrofit on protected buildings of rural origin, therefore giving a particular contribution to the open debate, by investigating the technical feasibility of measures for improving its performance, also including the implementation of renewable sources.

The research has its origins in the framework of "UIA OpenAgri – New skills for new Jobs in Peri-urban Agriculture" [32], a European project of sustainable and integrated urban development. The project is devoted to the creation of an innovative agri-food hub through the renovation of two historical rural buildings of Cascina Nosedo, an old farmhouse located in a peripheral and critical area of Milan.

Table 1. Features of selected studies on historical buildings energy renovation

	[20]	[28]	[23]	[33]	[24]^{L}	[2]	[3]	[25]	[22]	[26]	[24]^{H}	[21]	[27]
Use category			Residential			Off.	Edu.			Touristic		Ind.	Agri.
Country	IT	ES	BA	SE	IT	IT	IT	IT	UK	IT	IT	AT	IT
Walls insulation	TP-II	CI	EI	II/EI	EI	II	II	●	II	TP	EI	II	II
Roof insulation	TP		●	●	●	●	●	●			●	●	●
Floor insulation			●	●	●		●	●		●	●		●
New windows	2G	2G	●	2G/2Gi	●	2G	2Gi	●	2G	2G	●	●	2G
Air-to-water HP installation			●				●	●					
Water-to-water HP											●		
Ground source HP installation			●	●									
Wood boiler installation			●	●									
Other systems installation			●	●	●				●	●			
VMC installation		●	●						●		●		
PV installation					●	●	●	●		●	●		
ST installation			●		●			●	●	●	●		

^{L}: low investment scenario, ^{H}: high investment scenario, 2G: double glazed windows, 2Gi: additional internal double glazed windows, 3G: three glazed windows, Agri: agricultural, BA: Baltic area (Estonia, Finland and Sweden), CI: cavity insulation, Edu.: educational, EI: external insulation, II: internal insulation, Ind.: industrial, Off.: office, ST: solar thermal, PV: photovoltaic, VMC: Mechanical controlled ventilation.

METHOD

Approaching the retrofit of a historical building on the Italian territory, it is helpful to refer to the principles defined by the Ministry of Cultural Heritage, Activities and Tourism (MiBACT) within the document "Guidelines for the energy efficiency upgrade of the cultural heritage" [34]. As also clarified in de Santoli [35], neither ready to use solutions nor mandatory methodologies, are provided. Although the Guidelines provide a collection of suggested measures for historical buildings, it is evident that a wide degree of discretion occurs at the design stage. This is due to the fact that one should simultaneously consider any particular advice from the responsible local institution, as well as any specific, architectural and technical features that merit to be addressed. Therefore, a method composed by different steps should be adopted, as described in the following.

Architectural survey

As suggested in the above-mentioned document and anticipated in the Introduction section, the design phase has to be faced after a deep acknowledgement of the context, both from architectural and cultural point of view. To that end, the first step of the method is an architectural survey on the project site in order to notice, together with the analysis of the conservation state, the traditional elements and materials characterizing the cultural good. The architectural survey allows also the verification of the acquired dimensional data in order to develop the geometric model for the energy assessment of the buildings involved.

In addition to the regulatory framework and to the architectural survey, in the preliminary analysis, energy simulation of the building before retrofit (baseline) can be accomplished and, if data about energy consumptions are available, calibrated.

Hypothesis and design approach for the retrofit intervention

According to the information acquired by the architectural survey and taking into account the main criticalities of the buildings involved in the retrofit process, in order to build a simulation model for the energy assessment, the main architectural features of the buildings have to be defined, in such a way as to consider the main traditional elements.

Since there are no ready-to-use solutions in the mentioned Guideline, for finding the best solution, able at the same time to preserve the historical and cultural value of the construction and to ensure the lowest energy consumption, it is appropriate to propose a set of different solutions with increasing levels of energy performance and/or compliance with historical and architectural constraints.

Implementation of the energy model

In order to assess the effects of proposed retrofit scenarios, especially in terms of energy saving potential with respect to the pre-retrofit situation, an energy model describing the considered buildings has to be developed. According to the available information derived from the preliminary retrofit project, the model has to be designed through the definition of the buildings shape and construction characteristics, the partition of the thermal zones having different occupational profiles and internal gains, which is even more important in case of multifunctional end use of the buildings [36]. In order to assess the energy behaviour of the buildings, several tools can be adopted with different levels of detail. Among the tools available for properly assessing the dynamic behaviour of buildings, the software IESVE[†] can be adopted, as done for the present application (Result section). IESVE has been validated by Building Energy Simulation Test (BESTEST) based on ASHRAE Standard 140 and its capabilities have been recently compared with the EnergyPlus ones, with regard to different operation states of an educational building in Canada, obtaining slightest discrepancies [37]. The use of this software in energy simulation is gaining attention within research framework. Indeed, it has been used in several studies to assess, for instance, the energy consumption of a market building in New Taipei [38], the energy saving potential of an air handling unit within an office building in Singapore [39], the overheating risks and daylighting levels in high-rise residential buildings placed in London [40], and also the building energy demand at community level [41].

Thermal zonation and occupational profiles

The definition of the functions assigned to the thermal zones have to be carried out matching the possible new end use foreseen by the project, based on the needs of the

[†] IESVE for engineers (Integrated Environmental Solutions: Virtual Environment) is a 3D energy performance analysis software (https://www.iesve.com/support/userguides)

partners involved in it. Once the preliminary functions have been set, the next step regards the definition of the most proper occupational profiles, i.e., the time schedules modulating the heat gains associated to people, appliances and artificial lights. Among the other available and in force in the different contexts, the technical book SIA 2024 [42] offers an exhaustive characterization of many thermal zones, divided by function. Moreover, the parametrization adopted is accurate and well suitable for the integration as input in a dynamic simulation of a building energy model.

Energy simulation and estimation of energy needs and consumption

The first step, towards the definition of the energy model and its simulation, concerns the development of the geometric model of the buildings involved. Then the model has to be imported into the energy simulation tool detailing constructions, thermal loads and occupancy schedules of each thermal zone. The climatic conditions have to be selected in order to perform the calculation of the energy needs, importing the proper climatic file. Different outputs can be calculated by the energy simulation in order to explore the effects of the different retrofit strategies on thermal comfort, levels of indoor temperature and energy needs. Systems devoted to heating and cooling are usually assumed to be operating according to the occupancy schedule of each thermal zone.

Once the energy simulation has been run, accounting the building envelope retrofit measures, and the cooling and heating needs for each thermal zone have been evaluated, hypotheses and evaluations on the energy supply and use of different energy sources, including renewable ones, have to be given. Further, if the obtained results are not satisfying, according to a recursive approach, the method can be repeated from the beginning, changing the original energy retrofit hypothesis with the aim to improve the design process. The results obtained by different scenarios and approaches can be compared towards the optimal one.

The comparison of different energy retrofit solutions is useful in particular dealing with protected buildings, because the obtained results can influence the Superintendence judgement, in order to approve the most effective and compatible solution.

The different methodological steps are described in Figure 1 where, for the sake of generality, the possibility to compare the results obtained by the same mentioned method or by an energy audit, before and after the retrofit for the energy improvements evaluation, is also represented.

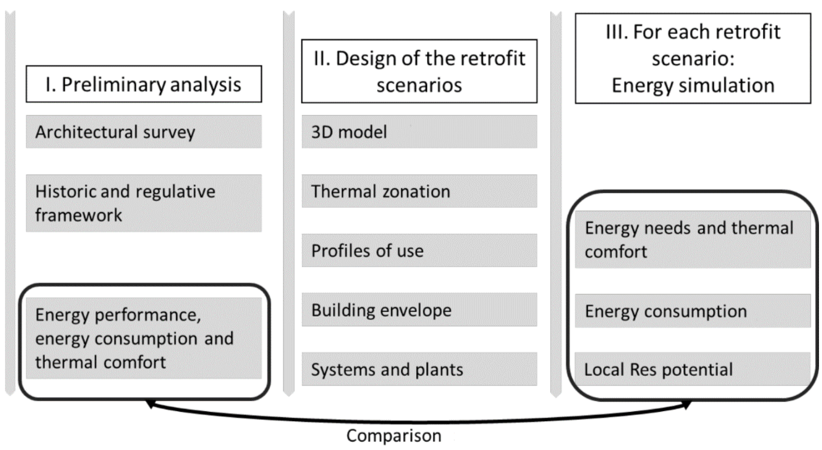


Figure 1. Methodological scheme

RESULTS AND DISCUSSION

The method described in the previous section is applied to the case study of Cascina Nosedo in order to verify its applicability, effectiveness and replicability.

The case study of Cascina Nosedo: Results of the architectural survey

The origin of Cascina Nosedo lies around 1600 with the realization of a productive farm. In 2013, after a long period of abusive occupation, the Municipality of Milano regained the site in order to valorise the historic and artistic relevance of this protected cultural heritage. The farmhouse area is composed by 11 buildings arranged in a traditional court scheme. As highlighted in Figure 2, the buildings that will undergo the retrofit are the two on the right (buildings 9 and 10), object of the present study. They have a single floor regular rectangular plan, for an overall floor surface of 337 m^2 for building 9 (B9) and 554 m^2 for building 10 (B10).

Through the architectural survey carried out on the project site, all the buildings' features have been scheduled in a check list, in order to have an overview on the conservation status, and to highlight the traditional elements and materials that should commonly be kept unaltered or re-established to restore the historical value of the site. In particular, consistently with the original features of the buildings of the farmhouse (Figure 3), the following elements should be considered: the visible clay brick pillars within the external walls, the external plaster, the wooden roof framing and the clay tiles roofing.

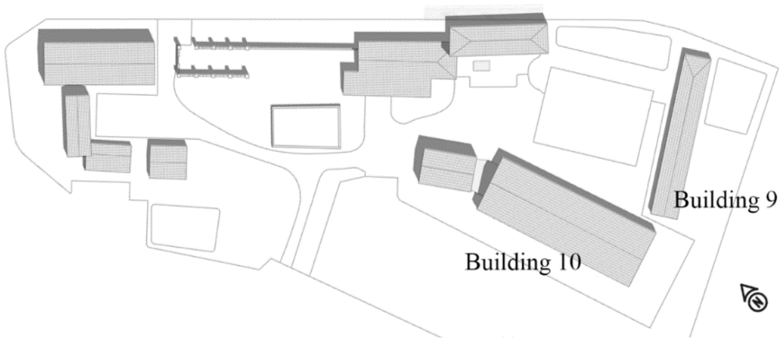


Figure 2. Masterplan of Cascina Nosedo and indication of the buildings analysed (B9 and B10)

Figure 3. Building 10 (left), building 9 (centre) and detail on conservation status (right)

The survey carried out on the project site has been useful to highlight the criticalities related both to the conservation state of the constructions and to the feasibility of the retrofit directives from Municipality of Milano advisors. The buildings 9 and 10, as well as the rest of the farmhouse, show diffuse deterioration signs, mainly related to the complete absence of a planned maintenance during the time. The plasterboard is detaching from the brick walls due to atmospheric corrosion, many clays on the roofs are damaged and the roof of building 10 has been roughly replaced with an asbestos shelter in the past, therefore, in order to restore the safety and serviceability of the two buildings, some preliminary interventions have to be accomplished.

Several criticalities arise also in the development of the energy retrofit simulation, indeed, it concerns the energy performance improvement of buildings mostly abandoned and composed by open and unheated spaces at the actual state. For this reason, the assessment of an energy audit, in order to define a reference case for the energy improvements evaluation, was not possible.

Design approach for the retrofit of Cascina Nosedo: Envelope scenarios

A first retrofit hypothesis concerned, together with the substitution of windows and roofs, the insulation of the opaque envelope from the outer side, a common solution for energy retrofits. However, considering the adverse opinion of the Superintendence on the feasibility of this first proposal, due to the alteration of the external aspect, it was necessary to develop an alternative retrofit solution, providing thermal insulation of the opaque envelope from the inner side.

Nevertheless, both the envelope scenarios have been kept into account for the whole design process, in order to evaluate their potential benefits.

Both solutions studied and proposed foresee an insulation with 10 cm wood fibre panels, provide the same walls thermal transmittance (0.26 W/m^{2}K), in line with the indexes in force [6], while different internal heat capacity (15 and 179 kJ/m^{2}K for internal and external insulation cases, respectively). Hence, the main difference between the two scenarios is represented by the relative position of the insulation layer with the respect of the thermal mass of the wall.

Energy model and thermal zonation of Cascina Nosedo

The two buildings have been divided into several new spaces (i.e., thermal zones) arranged in two floors in each building. Consequently, the façades are expected to be equipped with a proper number of windows in order to match the minimum requirements of daylight and natural ventilation. The definition of the functions assigned to the thermal zones has been carried out matching the new end use foreseen by the project, based on the needs of the partners involved in it. Once the preliminary functions have been set, the most proper occupational profiles (i.e., the time schedules modulating the heat gains associated to people, appliances and artificial lights) have been implemented. Since the buildings have been simulated before the publication of ISO 17772-1:2017 [43], that contains the precise weekly time schedules for each typology of space, the national reference in force [44] was compared to other available and more detailed references. Among them, the technical book SIA 2024 [42] according to the considerations reported in the Method sections. Therefore, in order to develop the thermal template of the model, the time schedules and the related internal gains for people, lights, appliances, ventilation rates and DHW referred to five different thermal zone typologies (kitchen, restaurant, laboratory, expo/conference room and office) were extrapolated from SIA 2024. Heating and cooling systems were assumed to be operating according to the occupancy schedule of each thermal zone. The sensible heating and cooling demands are computed by imposing the achievement of a set point temperature, 20 °C and 26 °C for the heating and cooling season[‡], respectively.

Hence, the whole model was finally divided into 8 thermal zones. The main features related to them are briefly described in Table 2, for both ground floor (GF) and first floor (1F).

As example, the appliances profiles assigned to the restaurant and office thermal zones follows (Figure 4), highlighting the different schemes of the time schedules adopted. While, the artificial lights profiles were defined by SIA2024 in a different way, with a constant value of electric consumption associated to a certain number of hours per day that has been adjusted on the occupancy profile of each thermal zone.

[‡] Heating season: 15th October-15th April, cooling season: 15th April-15th October {according to [45] for Milano (Zone E)}

Table 2. Thermal zones list and description

Code	Building-Floor	Name	Description	SIA schedule	Area [m^2]
TZ01	B9-GF	Kitchen	Kitchen of the restaurant	Kitchen	80
TZ02	B9-GF	Restaurant GF	Restaurant/food delivery	Restaurant	156
TZ03	B9-1F	Restaurant 1F	Restaurant/event room	Restaurant	207
TZ04	B9-1F	Kitchen lab	Innovation food laboratory	Laboratory	114
TZ05	B10-GF	Greenhouse lab	Technical space for the aquaponic greenhouse[§]	Laboratory	334
TZ06	B10-GF	Cycle officine	Laboratory for bicycle repairing	Laboratory	141
TZ07	B10-1F	Expo room	Polyfunctional area for expositions	Multi-purpose area	351
TZ08	B10-1F	Admin office	Administration offices	Office	188

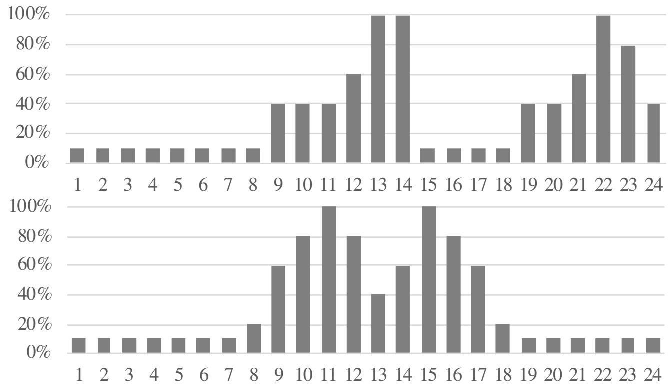


Figure 4. Example of time schedule profiles (restaurant aboveand office below) for appliances' internal heat gains [43]

Dynamic simulations by Integrated Environmental Solutions: Virtual Environment

According to the Method section, the geometric 3D model of the two buildings has been implemented by using SketchUp[**]. The model includes the 8 thermal zones and the surrounding shading context. Once imported into IESVE, the construction templates, the thermal loads templates and the occupancy time schedules of each thermal zone have been defined. Then, the climatic data have been assigned by selecting the climatic file of Milano_Linate_TMW[††]. The output obtained quantifies the thermal energy needs for heating, cooling and DHW, and the electricity demands for appliances and artificial lights for each thermal zone and grouped for building 9 and building 10.

Local renewable sources integration

A preliminary evaluation on the availability of local renewable potential, and the possibility of implementation of it for the building energy supply, has been carried out.

In order to explore solar energy conversion, an assessment about PV potential has been carried out, because Building Integrated Photovoltaics (BIPV) on roofs are suggested also in case of renovation of historic buildings in de Santoli [35]. Solar simulations have been performed on a 3D model of the area using the tool DIVA for Rhino[‡‡] adopting the validated Radiance/Daysim engine, over geometrical objects in Rhinoceros[§§]. The first step is a preliminary assessment of the surfaces, within the buildings in the model that better fit for a solar panels' installation, adopting the total annual solar radiation as benchmark. The results indicate good availability of solar potential. The implementation of BIPV has been envisioned only on the south-western roof's pitch of building 10 (1,130 kWh/m^2 per year of average total irradiation) since the actual roof has to be disposed anyway (asbestos).

[§] A greenhouse for developing an aquaponic activity is a component of the project
[**] www.sketchup.com/it/learn/resources
[††] The climate data used for all the analysis is the one of Milano Linate that is the nearest location to the area available in the validated Meteonorm database (www.meteonorm.com)
[‡‡] www.diva4rhino.com
[§§] www.rhino3d.com

Moreover, even if insufficient information was available for a predesign of the heating/cooling systems and plants, a hypothesis about the exploitation of the renewable local sources devoted to it was provided. The presence of a water treatment plant of Nosedo in the vicinity and of a sewer collector behind the area of Cascina Nosedo have been considered for the operation of HPs. The wastewater collected is characterized by interesting temperature profiles, between 10 and 20 °C around the year, giving the possibility to extract the heat from it through reversible HPs, connected to the wastewater collector by heat exchangers, and exploit it in the heating/cooling and DHW systems.

Outputs of the simulation: heating and cooling needs

For what concerns the energy performance of the two buildings in terms of heating and cooling needs, the results of the simulations have been schematized as reported in Table 3, highlighting the comparison between the two envelope scenarios, according to the results obtained by the energy simulations.

As main results, the internal insulation implies a decrease of 18% of heating energy need (and a decrease of 9% in the hours of heating system activation) but an increase of 16% in related peak, affecting the size of the heating system. Cooling side, internal insulation implies an increase of 8% of energy need, maintaining the same pick and the same number of hours of system activation.

It is possible to note that, due to the destination of the buildings (non-residential) and to the assumed profile of use that is rather intermittent, there are not significant differences in terms of energy needs on yearly basis in the two scenarios (internal and external insulation).

Table 3. Energy needs for the whole building model (buildings 9 and 10)

	External insulation		Internal insulation	
	Heating	Cooling	Heating	Cooling
Total [MWh/yr]	39.9	33.7	32.8	36.4
Total [kWh/m^{2}yr]	25.4	21.4	20.9	23.1
Peak [kW]	107.9	47.0	124.9	47.7
Working hours [h]	2,641	2,864	2,404	2,863

For a better understanding of the energy behaviour of the buildings depending on the two envelopes configurations, the internal temperatures in free floating during the year have been plotted and compared to external and set point temperature. As example, Figure 5 and Figure 6 show the result for a winter week and a summer week, respectively, of an office thermal zone (TZ08, administrative office). Since external insulation implies a slower response to the temperature variation than the internal insulation, the representation underlines the light benefits of external insulation on temperature profiles.

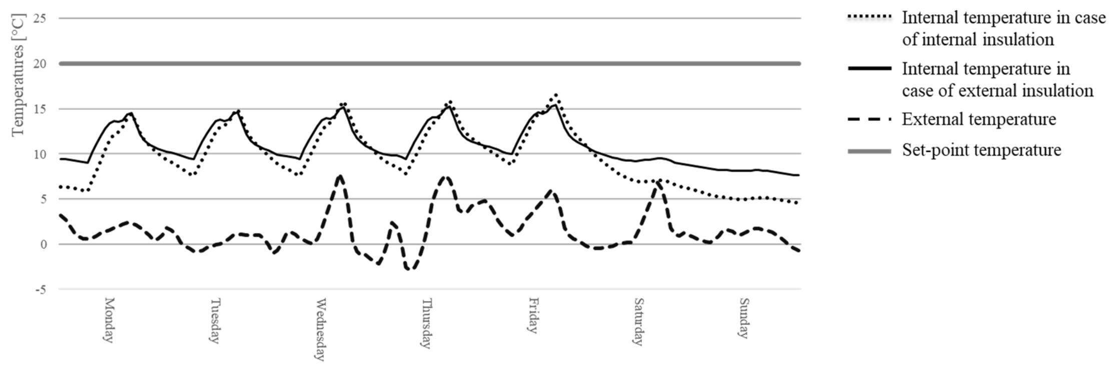


Figure 5. Temperatures profiles for internal and external insulation scenarios of thermal zone TZ08 (office) during a winter week

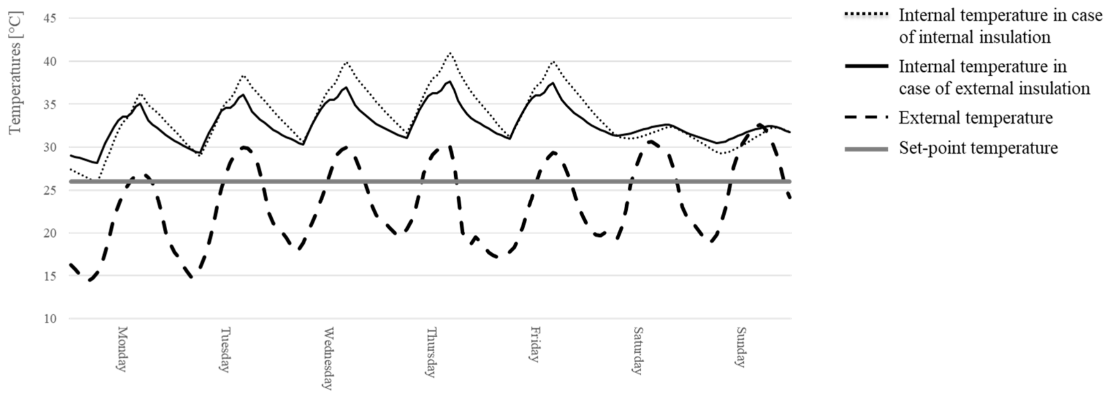


Figure 6. Temperature profiles for internal and external insulation scenarios of thermal zone TZ08 (office) during a summer week

Estimated energy needs in similar case studies

It is well known that buildings energy needs simulated in different studies, even in the similar field of investigation, are inevitably diverse. This is due to obvious reasons, such as different climatic conditions, buildings envelope dimensions, shapes and features, use categories, etc. Other less evident reasons can be referred to the adoption of different calculation methods or different simulation tools and different assumptions in defining the building energy simulation models. Concerning the latter, for instance, the outcomes of the tests for the comparison of different users of the standard [46] attested that diverse energy modellers may obtain results, differing by as much as 20% for the same building in the same climate, as reported in the standard itself.

Aware of these criticalities, based on the literature review reported in the Introduction section, a selection of Italian case studies has been considered for comparing at least the order of magnitude of the results obtained in the present case study. The selection of the case studies, summarized below mentioning the main envelope retrofit features, is based on the ones that reveal similar climatic conditions of Cascina Nosedo (i.e., related to locations falling within the range of Heating Degree Days [47] 2,100-3,000, which correspond to the national climatic classification “Zone E”) and for which data of estimated energy needs are available.

For the retrofit of the historical school building, having a load-bearing masonry made of full clay bricks, located in Milan and analysed in Ferrari and Romeo [3], a space heating need of 37 kWh/m^2 per year and a space cooling need of 28 kWh/m^2 per year were estimated after the assessed retrofit scenario (insulation of external walls from inside, of basement ceiling and ground floors, and installation of additional internal double-glazed windows). While, for the retrofit of a hotel building in Turin assessed in Buso *et al*. [25] (i.e., external insulation of vertical and horizontal opaque envelope and installation of new windows), a space heating need of 20 kWh/m^2 per year and a space cooling need of 38 kWh/m^2 per year were estimated. A set of retrofit solutions (i.e., the installation of double-glazing windows and the insulation of both vertical stones walls and horizontal floor of the unconditioned loft below the pitched roof) was assessed for an aged typical farmhouse located in Perugia, Central Italy, in Menconi *et al*. [27]. In this case, the optimal solution results in a space heating energy need of 56 kWh/m^2 per year, while no cooling system is foreseen.

In Becchio *et al*. [24], two refurbishment options (implying high and low investment costs, based on different thermal performances, original or new use category and conditioned volume) for a traditional rural building located in Livorno Ferraris (a small town in Northern Italy) were analysed. Both scenarios foresee the insulation of the external walls and roof, the realization of insulated and ventilated floor over the ground, and the replacement of windows with new ones having different performances based on different targets. Space heating and cooling needs around 35 kWh/m^2 per year and 8 kWh/m^2 per year, respectively, are reported for the low investment scenario, while around 20 kWh/m^2 per year and 8 kWh/m^2 per year for the high investment scenario.

Figure 7 shows the energy needs of the mentioned case of studies together with the ones evaluated for Cascina Nosedo. Results obtained for the two energy retrofit scenarios of this last are in the ranges obtained for the mentioned selected case of studies, i.e., 20 ÷ 37 kWh/m^2 for heating and 8 ÷ 28 kWh/m^2 for cooling, demonstrating the global consistency of method adopted and presented here.

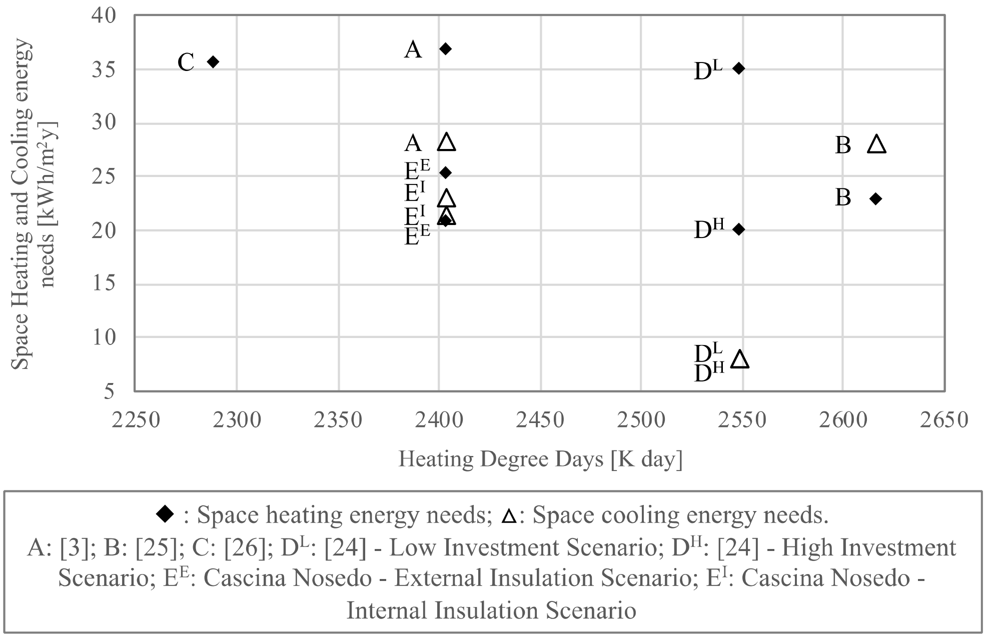


Figure 7. Selected case studies' energy needs and the Cascina Nosedo ones

Focus on thermal comfort implications

In order to explore the effects on comfort, among the several thermal zones simulated, a focus has been done on the one that revealed the larger thermal energy needs difference in relation to the two insulation scenarios: the so-calledTZ05 (Greenhouse Lab).

To that end, the operative temperature, able to combine the effect of air temperature and mean radiant temperature, was taken into account because it represents more accurately the performance of the building envelope in contributing to overall thermal comfort sensation. In fact, operative temperature is a fundamental parameter for defining indoor environmental conditions based on the human body heat balance according to Fanger [48]. The Fanger equation is used to determine (according to conventional seasonal clothing level and standard air humidity and velocity) reference operative temperature ranges related to the building use, which corresponds to defined activity levels. The operative temperature limits for the building uses connected to moderate activity level are a minimum 20 °C in winter and a maximum 26 °C in summer. Despite the influence of operative temperature on the real building energy need, it is commonly neglected in simplified building energy assessment, which considers only the air temperature. As a matter of fact, in case of unfavourable radiant temperatures, the air temperature set-point is usually corrected by the users in order to adjust the indoor condition to compensate the radiative component, and the consequent overuse of the active climatization systems causes an unpredicted increase of building energy consumption.

In order to explore this issue, a comparison of the operative temperatures, together with air temperatures, related to the two insulation scenarios for the selected thermal zone is reported in Figure 8 and Figure 9, for a winter and a summer week.

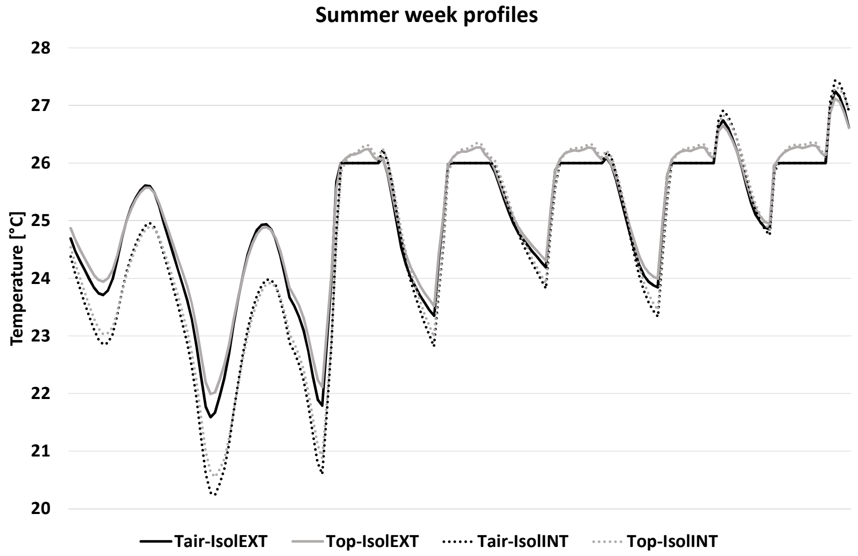


Figure 8. Operative and air temperatures profiles for internal and external insulation scenarios of thermal zone TZ05 (Greenhouse Lab) during a summer week

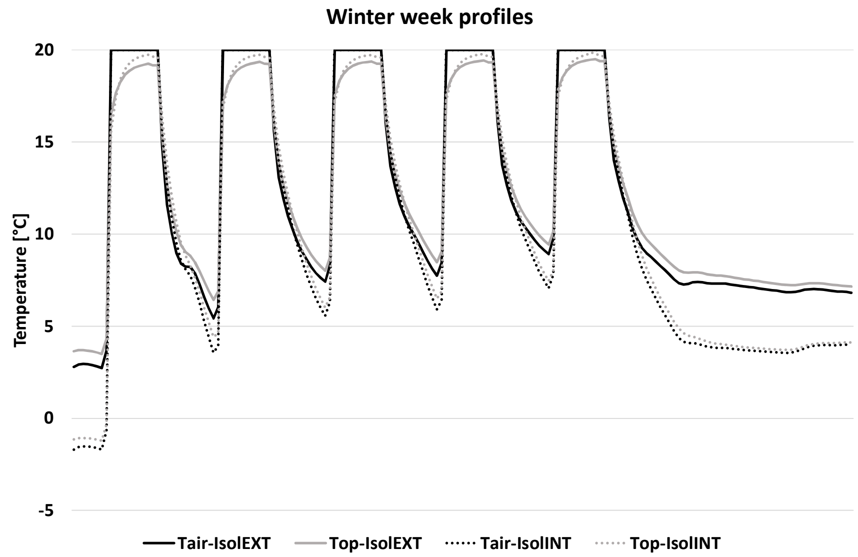
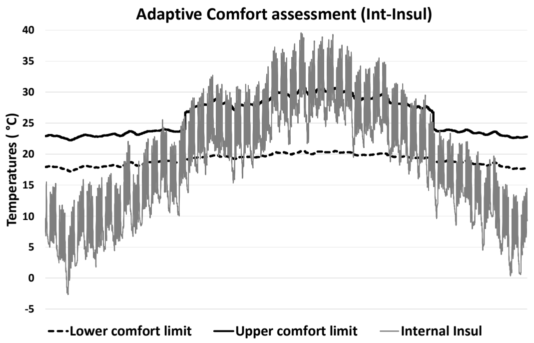


Figure 9. Operative and air temperatures profiles for internal and external insulation scenarios of thermal zone TZ05 (Greenhouse Lab) during a winter week

Looking at the two plotted charts, it can be noted that the operative temperatures are quite similar in the two cases (internal and external insulation), likely due to the same very low thermal transmittance of the walls, in line with the strictest indexes in force, that affect similar values of surfaces temperatures. Moreover, during the occupancy hours, driven by the air temperature set points, the operative temperatures of the two cases reach values similar to the imposed air temperature, having the maximum differences less than 1 °C, therefore, both the cases satisfy similar thermal comfort conditions.

Additionally, the adaptive comfort approach has also been taken into account. This approach considers the social and psychological aspects of thermal perception and assumes that the users' thermal expectations are actually connected with the outside climatic conditions on a variable base [49]. More in detail, it considers the ability of human beings to adapt themselves to the environmental conditions through conscious or unconscious changes in their metabolic rate or clothing level, and to interact with the environment in order to adapt it to their needs through available environmental controls, such as openable windows, thermostats, fans switches, etc.

Hence, based on the adaptive formulation considered in Ferrari and Zanotto [50], the adaptive comfort range referred to "very good" indoor conditions (i.e., 90% of acceptability) has been calculated. The comfort band together with the temperatures simulated in free floating of the two cases are shown in Figure 10.



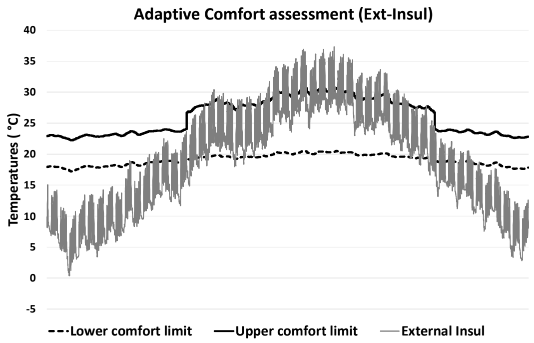


Figure 10. Adaptive comfort band and free-floating annual temperatures profiles for internal (left) and external (right) insulation scenarios of thermal zone TZ05 (Greenhouse Lab)

Analysing the annual performance of the two cases simulated in free floating, the Discomfort Degree Hours (DDH), i.e., the number of hours in which indoor conditions are outside the comfort limits and in which heating or cooling loads are required, have been calculated according to Blázquez *et al*. [28].

For the selected thermal zones, Table 4 reports the heating and cooling energy needs, assessed by simulating the conventional set points 20 ÷ 26 °C, and the adaptive DDH[***], underlining the same trend (during winter internal insulation is better, while during summer external insulation is better).

Table 4. Heating and cooling needs and DDH for the selected zone

	External insulation		Internal insulation	
	Heating	Cooling	Heating	Cooling
Simulation with set points 20 ÷ 26 °C				
Energy needs [MWh/yr]	9.67	6.29	8.41	7.14
Simulation in free floating				
DDH	6,177.8	1,782.7	5,877.2	2,655.6

Building-Integrated Photovoltaics system on the roof

Tuning to BIPV, for the roof integration on the South-western pitch of building 10, the suitable area for the panels is 328 m^2 wide. This configuration has been simulated through the tool PVSyst[†††] obtaining the annual yields of different PV technologies (mono-crystalline, poly-crystalline, thin film), reported in Table 5.

Table 5. Results achieved through PVSyst for different BIPV technologies on the roof of building 10

	Nominal power [kW]	Annual yield [MWh/yr]
Mono-crystalline	52.5	50.7
Poly-crystalline	49.2	47.5
Thin film	32.8	31.7

[***] Not only does this index measure the amount of time that the indoor conditions fall outside the comfort range, but also quantifies how big the temperature difference gets

[†††] www.pvsyst.com

As already mentioned, the design of the plant configuration is under definition, because of the several obstacles encountered during the project development. Nevertheless, some considerations, based on the results discussed in this section, can be carried out. A good solution could be to satisfy the energy needs of the buildings with a reversible HP both for cooling, heating and DHW. It was assumed to integrate the sewer collector as the heat source in order to optimise the performance of the HP thank to the proper level of temperature. A preliminary estimation of the total electric demand needed by the HP to satisfy the buildings' energy needs has been accomplished and compared to the yearly PV potential, as reported in Table 6. As Hepbasli *et al*. [51] suggest, the performance indexes of a Waste Water Heat Pump (WWHP) depend on the boundary and application conditions (inlet and outlet temperatures of the heat exchanger, system typology, etc.) and can vary in a wide range. In our case, without the needed details, a range of COP was adopted [51] in first analysis, and results are reported in Table 6.

Table 6. Comparison of the total electricity demand with the theoretical PV electricity production

	Thermal needs [MWh/yr]	HP η_s^{**} [-]	Electric demand [MWh/yr]	Tot. electric demand [MWh/yr]	PV potential [MWh/yr]
Heating	36.5*	4-5	9.1-7.3		
Cooling	35.0*	3-4	11.7-8.8		
DHW	3.8	3-4	1.3-1	139.6-134.6	50.7***
Lights			46		
Appliances			71.5		

* Average values between internal and external scenario results
** Seasonal performance coefficient for WWHP [51]
*** BIPV previously calculated in the case of mono-crystalline technology

Further discussion of the achieved results

As concerns the evaluation of the best envelope scenario for the case study retrofit, beyond the results obtained in terms of energy needs, the features of the envelope to be evaluated regard the dynamic building behaviour and architectural integration. For what concerns the architectural aspects, a sensitive topic dealing with the retrofit of a historical building, the external insulation involves a modification of the exterior aspect, while the case with insulation from inside results in a slightly reduced net internal space. Concerning the thermal inertia of the envelope, comparing the two different configurations, it was observed that the external insulation implies a slower response and adaptation to the temperature variation than the internal insulation. This is a consequence of the insulation strategy that includes, with external insulation, or excludes, with internal insulation, the brick layer in the computation of the effective thermal mass of the envelope.

In terms of total needs (heating and cooling), the simulations accomplished show negligible difference between the two alternatives, while, in terms of thermal power, the external insulation scenario provides a slightly lower peak. Concluding, given the previous considerations, it can be stated that, having an intermitting control system regime, serving many adjacent zones thermally independent and considering the constrains involved in protected building retrofit, the internal insulation scenario could be the optimal solution in terms of energy behaviour, architectural integration and feasibility in this particular case of study. As mentioned, since the buildings are currently mostly abandoned and composed by open and unheated spaces, the definition of a reference case towards comparison of the related energy performances and evaluation of the energy improvement is not possible, additionally, in this stage, monitoring data are not available.

Of course, the results obtained are strongly affected by the software calculation method and by the assumptions carried out on the thermal zones functions that could slightly change in the definitive version of the project.

Conversely, on the supply side, although there are no defined rules to prevent BIPV in protected buildings and rather the national guidelines for energy retrofit in historical buildings (i.e., [34, 35]) contemplate BIPV on the roofs, the official opinion of the Superintendence made us lose the benefit of PV generation. The opportunity of PV integration is even more significant if it is considered as supply system, in a preliminary hypothesis, an electrically-powered HP, through which all the energy demand is translated in electricity consumption. Fortunately, the possibility of adopting wastewater as heat source for the HP was not discarded. Nonetheless, the definition and the design of the system configuration is still in progress, because of the several obstacles encountered during the development of the project, such as economic, managerial and infrastructural issues.

After our elaborations, the renovation of Cascina Nosedo complex has been designed and the executive project foresees some differences in relation to heating and cooling systems, Renewable Energy Sources (RES) integration and buildings to be retrofitted. Therefore, further development of our work will regard the energy simulations once the executive project is completed and a monitoring activity once building 10 is completed and in operation.

CONCLUSIONS

This article presents the results of a study aimed at the evaluation of the energy retrofit of rural protected buildings. The study shows that achieving good energy performance in case of protected buildings is quite challenging due to architectural, historical and cultural constraints. Therefore, guidelines and standards at country level and robust methodological approaches for framing properly the issue and supporting results are needed. In this framework, regardless of the tools used in the particular case study described, the method proposed and applied here has proven reliable and can be replicated in other similar cases of protected buildings. The design and comparison of different energy retrofit solutions is strongly suggested, especially when dealing with protected buildings and superintendence judgement.

Based on results obtained for the case study considered here, in terms of total annual needs (heating and cooling), the simulations accomplished show negligible difference between the two alternatives, while, in terms of thermal power, the external insulation scenario provides a slightly lower peak. In addition, the annual energy needs for space heating and for space cooling obtained for the case study are comparable to the ones reported in selected studies from literature.

ACKNOWLEDGMENT

The authors thank the European UIA for supporting OpenAgri project, Comune di Milano for promoting the project and all the involved partners for collaborating in the research.

REFERENCES

1. Buildings Performance Institute Europe (BPIE), Europe's Buildings Under the Microscope: A Country-by-Country Review of the Energy Performance of Buildings, Report, Bruxelles, Belgium, 2011, http://bpie.eu/wp-content/uploads/2015/10/HR_EU_B_under_microscope_study.pdf, [Accessed: 10-April-2019]
2. Cellura, M., Ciulla, G., Guarino, F. and Longo, S., Redesign of a Rural Building in a Heritage Site in Italy: Towards the Net Zero Energy Target, *Buildings*, Vol. 7, No. 3, pp 68, 2017, https://doi.org/10.3390/buildings7030068
3. Ferrari, S. and Romeo, C., Retrofitting Under Protection Constraints According to the Nearly Zero Energy Building (NZEB) Target: The Case of an Italian Cultural

Heritage's School Building, *Energy Procedia*, Vol. 140, pp 495-505, 2017, https://doi.org/10.1016/j.egypro.2017.11.161

4. Martínez-Molina, A., Tort-Ausina, I., Cho, S. and Vivancos, J. L., Energy Efficiency and Thermal Comfort in Historic Buildings: A Review, *Renewable and Sustainable Energy Reviews*, Vol. 61, pp 70-85, 2016, https://doi.org/10.1016/j.rser.2016.03.018
5. European Parliament, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (Recast), Official Journal of the European Union, L 153/13, 2010, https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF, [Accessed: 10-April-2019]
6. Italian Ministry of Economic Development (MiSE) with Ministries of Environment and Protection of Territory and Sea, of Infrastructures and Transports, of Health and of Defence, Inter-ministerial Decree 26/06/2015, Application of the Energy Performances Calculation Methodologies and Definition of Previsions and Minimum Requirements of Buildings (in Italian), Official Journal of the Italian Republic, 2015.
7. Italian Ministry of Economic Development (MiSE), Law 03/08/2013, Conversion, with Modifications, of the Law Decree 4 June 2013, No. 63, Urgent Provisions for the Implementation of Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010, on the Energy Performance of Buildings for the Definition of Infringement Procedures Initiated by the European Commission, as well as Other Provisions on Social Cohesion (in Italian), Official Journal of the Italian Republic, 2013.
8. Ascione, F., De Rossi, F. and Vanoli, G. P., Energy Retrofit of Historical Buildings: Theoretical and Experimental Investigations for the Modelling of Reliable Performance Scenarios, *Energy and Buildings*, Vol. 43, No. 8, pp 1925-1936, 2011, https://doi.org/10.1016/j.enbuild.2011.03.040
9. Baggio, M., Tinterri, C., Dalla Mora, T., Righi, A., Peron, F. and Romagnoni, P., Sustainability of a Historical Building Renovation Design Through the Application of Leed® Rating System, *Energy Procedia*, Vol. 113, pp 382-389, 2017, https://doi.org/10.1016/j.egypro.2017.04.017
10. Mazzarella, L., Energy Retrofit of Historic and Existing Buildings. The Legislative and Regulatory Point of View, *Energy and Buildings*, Vol. 95, pp 23-31, 2015, https://doi.org/10.1016/j.enbuild.2014.10.073
11. Galatioto, A., Ciulla, G. and Ricciu, R., An Overview of Energy Retrofit Actions Feasibility on Italian Historical Buildings, *Energy*, Vol. 137, pp 991-1000, 2017, https://doi.org/10.1016/j.energy.2016.12.103
12. Cho, H. M., Wi, S., Chang, S. J. and Kim, S., Hygrothermal Properties Analysis of Cross-Laminated Timber Wall with Internal and External Insulation Systems, *Journal of Cleaner Production*, Vol. 231, pp 1353-1363, 2019, https://doi.org/10.1016/j.jclepro.2019.05.197
13. Rosti, B., Omidvar, A. and Monghasemi, N., Optimum Position and Distribution of Insulation Layers for Exterior Walls of a Building Conditioned by Earth-Air Heat Exchanger, *Applied Thermal Engineering*, Vol. 163, pp 1-7, 2019, https://doi.org/10.1016/j.applthermaleng.2019.114362
14. Cheng, F., Zhang, X. and Su, X., Comparative Assessment of External and Internal Insulation for Intermittent Air-Conditioned Bedrooms in Shanghai, *Procedia Engineering*, Vol. 205, pp 50-55, 2017, https://doi.org/10.1016/j.proeng.2017.09.933
15. Asan, H., Investigation of Wall's Optimum Insulation Position from Maximum Time Lag and Minimum Decrement Factor Point of View, *Energy and Buildings*, Vol. 32, No. 2, pp 197-203, 2000, https://doi.org/10.1016/S0378-7788(00)00044-X

16. Webb, A. L., Energy Retrofits in Historic and Traditional Buildings: A Review of Problems and Methods, *Renewable and Sustainable Energy Reviews*, Vol. 77, pp 748-759, 2017, https://doi.org/10.1016/j.rser.2017.01.145
17. Ferrari, S. and Riva, A., Insulating a Solid Brick Wall from Inside: Heat and Moisture Transfer Analysis of Different Options, *Journal of Architectural Engineering*, Vol. 25, No. 1, 04018032, 2019, https://doi.org/10.1061/(ASCE)AE.1943-5568.0000334
18. Kovacic, I., Summer, M. and Achammer, C., Strategies of Building Stock Renovation for Ageing Society, *Journal of Cleaner Production*, Vol. 88, pp 349-357, 2015, https://doi.org/10.1016/j.jclepro.2014.04.080
19. Roberti, F., Oberegger, U. F., Lucchi, E. and Troi, A., Energy Retrofit and Conservation of a Historic Building Using Multi-Objective Optimization and an Analytic Hierarchy Process, *Energy and Buildings*, Vol. 138, pp 1-10, 2017, https://doi.org/10.1016/j.enbuild.2016.12.028
20. Ciulla, G., Galatioto, A. and Ricciu, R., Energy and Economic Analysis and Feasibility of Retrofit Actions in Italian Residential Historical Buildings, *Energy and Buildings*, Vol. 128, pp 649-659, 2016, https://doi.org/10.1016/j.enbuild.2016.07.044
21. Gourlis, G. and Kovacic, I., A Study on Building Performance Analysis for Energy Retrofit of Existing Industrial Facilities, *Applied Energy*, Vol. 184, pp 1389-1399, 2016, https://doi.org/10.1016/j.apenergy.2016.03.104
22. Salem, R., Bahadori-Jahromi, A., Mylona, A., Godfrey, P. and Cook, D., Investigating the Potential Impact of Energy-Efficient Measures for Retrofitting Existing UK Hotels to Reach the Nearly Zero Energy Building (nZEB) Standard, *Energy Efficiency*, Vol. 12, pp 1577-1594, 2019, https://doi.org/10.1007/s12053-019-09801-2
23. Alev, Ü., Eskola, L., Arumägi, E., Jokisalo, J., Donarelli, A., Siren, K., Broström, T. and Kalamees, T., Renovation Alternatives to Improve Energy Performance of Historic Rural Houses in the Baltic Sea Region, *Energy and Buildings*, Vol. 77, pp 58-66, 2014, https://doi.org/10.1016/j.enbuild.2014.03.049
24. Becchio, C., Corgnati, S. P. and Spigliantini, G., Evaluation of Refurbishment Alternatives for an Italian Vernacular Building Considering Architectural Heritage, Energy Efficiency and Costs, *Energy Procedia*, Vol. 133, pp 401-411, 2017, https://doi.org/10.1016/j.egypro.2017.09.370
25. Buso, T., Becchio, C. and Corgnati, S. P., NZEB, Cost-and Comfort-optimal Retrofit Solutions for an Italian Reference Hotel, *Energy Procedia*, Vol. 140, pp 217-230, 2017, https://doi.org/10.1016/j.egypro.2017.11.137
26. Congedo, P. M., Baglivo, C., Zacà, I., D'Agostino, D., Quarta, F., Cannoletta, A., Marti, A. and Ostuni, V., Energy Retrofit and Environmental Sustainability Improvement of a Historical Farmhouse in Southern Italy, *Energy Procedia*, Vol. 133, pp 367-381, 2017, https://doi.org/10.1007/978-94-024-0902-4_15
27. Menconi, M. E., Chiappini, M., Hensen, J. L. and Grohmann, D., Thermal Comfort Optimisation of Vernacular Rural Buildings: Passive Solutions to Retrofit a Typical Farmhouse in Central Italy, *Journal of Agricultural Engineering*, Vol. 48, No. 3, pp 127-136, 2017, https://doi.org/10.4081/jae.2017.668
28. Blázquez, T., Ferrari, S., Suárez, R. and Sendra, J. J., Adaptive Approach-Based Assessment of a Heritage Residential Complex in Southern Spain for Improving Comfort and Energy Efficiency Through Passive Strategies: A Study Based on a Monitored Flat, *Energy*, Vol. 181, pp 504-520, 2019, https://doi.org/10.1016/j.energy.2019.05.160
29. Fecondo, P. and Moca, G., The ELENA Programme in the Province of Chieti-A Public Private Partnership Best Practice Improving Energy Efficiency of Buildings and Public Lighting Systems, *Journal of Sustainable Development of Energy, Water*

and Environment Systems, Vol. 3, No. 3, pp 230-244, 2015, https://doi.org/10.13044/j.sdewes.2015.03.0018
30. Ricciu, R., Galatioto, A., Besalduch, L. A., Desogus, G. and Di Pilla, L., Building Wall Heat Capacity Measurement Through Flux Sensors, *Journal of Sustainable Development of Energy, Water and Environment Systems*, Vol. 7, No. 1, pp 44-56, 2019, https://doi.org/10.13044/j.sdewes.d6.0234
31. Ferrari, S. and Zanotto, V., Building Envelope and Thermal Balance, in: *Building Energy Performance Assessment in Southern Europe*, pp 1-20, Springer International Publishing, 2016.
32. Urban Innovative Actions (UIA), OpenAgri, Lille, France, https://www.uia-initiative.eu/en/uia-cities/milan, [Accessed: 10-April-2019]
33. Milić, V., Ekelöw, K., Andersson, M. and Moshfegh, B., Evaluation of Energy Renovation Strategies for 12 Historic Building Types Using LCC Optimization, *Energy and Buildings*, Vol. 197, pp 156-170, 2019, https://doi.org/10.1016/j.enbuild.2019.05.017
34. Italian Ministry of Cultural Heritage, Activities and Tourism (MIBACT), Guidelines for the Improvement of Energy Efficiency in the Cultural Heritage (in Italian), 2015, https://soprintendenza.pdve.beniculturali.it/wp-content/uploads/2018/04/Linee_indirizzo_miglioramento_efficienza_energetica_nel_patrimonio_culturale.pdf, [Accessed: 10-April-2019]
35. de Santoli, L., Guidelines on Energy Efficiency of Cultural Heritage, *Energy and Buildings*, Vol. 86, pp 534-540, 2015, https://doi.org/10.1016/j.enbuild.2014.10.050
36. Ferrari, S. and Zanotto, V., Implications of the Assumptions in Assessing Building Thermal Balance, in: *Building Energy Performance Assessment in Southern Europe*, pp 35-45, Springer International Publishing, 2016, https://doi.org/10.1007/978-3-319-24136-4_3
37. Al-janabi, A., Kavgic, M., Mohammadzadeh, A. and Azzouz, A., Comparison of Energyplus and IES to Model a Complex University Building Using Three Scenarios: Free-Floating, Ideal Air Load System, and Detailed, *Journal of Building Engineering*, Vol. 22, pp 262-280, 2019, https://doi.org/10.1016/j.jobe.2018.12.022
38. Lin, P. H., Chang, C. C., Lin, Y. H. and Lin, W. L., Green BIM Assessment Applying for Energy Consumption and Comfort in the Traditional Public Market: A Case Study, *Sustainability*, Vol. 11, No. 17, pp 2-26, 2019, https://doi.org/10.3390/su11174636
39. Mihara, K., Sekhar, C., Takemasa, Y., Lasternas, B. and Tham, K. W., Thermal Comfort and Energy Performance of a Dedicated Outdoor Air System with Ceiling Fans in Hot and Humid Climate, *Energy and Buildings*, Vol. 203, pp 1-13, 2019, https://doi.org/10.1016/j.enbuild.2019.109448
40. Nebia, B. and TabetAoul, K., Overheating and Daylighting; Assessment Tool in Early Design of London's High-Rise Residential Buildings, *Sustainability*, Vol. 9, No. 9, pp 1-23, 2017, https://doi.org/10.3390/su9091544
41. McCallum, P., Patidar, S., Jenkins, D., Peacock, A., Robu, V., Andoni, M. and Flynn, D., The Use of Demand Modelling for Community Energy Analysis, *Proceedings of the 2018 IEEE International Symposium on Circuits and Systems (ISCAS)*, pp 1-5, Firence, Italy, May 27-30, 2018.
42. SIA Leaflet 2024, *Standard Terms of Use for Energy and Building Technology* (in German), Verlag SIA, Zürich, Switzerland, 2006.
43. International Organization for Standardization (ISO), Standard ISO 17772-1, Energy Performance of Buildings – Indoor Environmental Quality – Part 1: Indoor Environmental Input Parameters for the Design and Assessment of Energy Performance of Buildings, Geneva, Switzerland, 2017.

44. Italian Unification Body (UNI), UNI/TS 11300-5:2016, Energy Performance of Buildings – Part 5: Evaluation of Energy Performance for the Classification of Building (in Italian), Technical Specification, Milan, Italy, 2017.
45. Decree n. 412 of 26/08/1993, Regulation Laying Down Rules for the Design, Installation, Operation and Maintenance of Heating Systems in Buildings in Order to Contain Energy Consumption, in Implementation of Art. 4, Paragraph 4, of the Law of 9 January 1991, N. 10 (in Italian), Official Journal of the Italian Republic, 1991, http://www.taed.unifi.it/fisica_tecnica/Gabriele/02b-L10%20e%20DPR%20412.pdf, [Accessed: 10-April-2019]
46. International Organization for Standardization (ISO), Standard ISO 13790:2008, Energy Performance of Buildings – Calculation of Energy Use for Space Heating and Cooling, Geneva, Switzerland, 2008.
47. D'Amico, A., Ciulla, G., Panno, D. and Ferrari, S., Building Energy Demand Assessment Through Heating Degree Days: The Importance of a Climatic Dataset, *Applied Energy*, Vol. 242, pp 1285-1306, 2019, https://doi.org/10.1016/j.apenergy.2019.03.167
48. Fanger, P. O., *Thermal Comfort: Analysis and Applications on Environmental Technology*, Danisch Technical Press, Copenhagen, Denmark, 1970.
49. Ferrari, S. and Zanotto, V., Thermal Comfort Approaches and Building Performance, in: *Building Energy Performance Assessment in Southern Europe*, pp 47-60, Springer International Publishing, 2016, https://doi.org/10.1007/978-3-319-24136-4_4
50. Ferrari, S. and Zanotto, V., Energy Performance Analysis of Typical Buildings, in: *Building Energy Performance Assessment in Southern Europe*, pp 79-98, Springer International Publishing, 2016.
51. Hepbasli, A., Biyik, E., Ekren, O., Gunerhan, H. and Araz, M., A Key Review of Wastewater Source Heat Pump (WWSHP) Systems, *Energy Conversion and Management*, Vol. 88, pp 700-722, 2014, https://doi.org/10.1016/j.enconman.2014.08.065

Paper submitted: 18.04.2019
Paper revised: 15.04.2020
Paper accepted: 16.04.2020