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An overview of energy retrofit actions feasibility on Italian historical buildings

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Italian energy policy has determined important keystones in building energy efficiency regulations and their application throughout the country. However, there is still much work to be done in order to make sustainable societies and territories, especially in historical contexts that have the greatest potentiality of energy saving. In detail, in the framework of conservation, restoration, refurbishment, and retrofit actions, the debate among scientists, administrators and skilled people is still open due to the many aspects yet to be considered and solved. In this paper, the state of the art of Italian residential building heritage has been reviewed, while energy retrofit issues and viable solutions have been investigated by collecting literature examples and experiences, focusing on common retrofit measures on historical buildings per thematic area. Finally, the advantages and disadvantages of each action have been discussed.

Anyway, two main aspects have to be solved yet: the high Payback Times and the restriction about Renewable Energy Sources installation on this kind of buildings.

1. Introduction

As is well-known, the greatest energy saving potential lies in a residential building sector that is responsible for approximately 40% of global primary energy demand [1,2]. In this way, European energy policy [3e5] improved energy retrofit actions on buildings and HVAC systems and several noticeable results have already been achieved [6].

In Europe, a large part of the existing building stock shows an average yearly energy demand for space heating and Domestic Hot Water (DHW) production, ranging between 150 and 300 kWh/ m^{2}year [7]. Under such circumstances, even basic energy retrofit actions may significantly reduce the building energy demand, resulting in significant energy savings, and worldwide, the retrofit actions have to be accurately chosen, to correctly identify the best refurbishment measures to apply on existing buildings [8e10].

More difficult is applying an adequate refurbishment action on old buildings, in particular in Italy, since measures are difficult to implement due to the strict regulation of these buildings' "protected status". Therefore, in the fields of conservation, restoration, integrated refurbishment, retro-commissioning and retrofit actions, the scientific and professional debate is still open, because there are many aspects yet to be considered and solved [11], especially since, in Italy, the energy retrofit actions are often focused on modern buildings, generally built after the Second World War.

As reported in the UNESCO World Heritage List, Italy has 4.7% of the world architectural heritage, occupying 46% of the entire country [12]. More in detail, looking at the state of the art of building heritage, over 4,000,000 of the 5,367,000 worldwide monuments are in Italy and there are many buildings built before 1919 that have public or residential use.

Therefore, the existing historical building stock is wide, heterogeneous and composed of a great amount of buildings with poor energy characteristics.

In this framework, Italian regulation recommends building energy requirements [13] and the revised UNI TS 11300 parts 1-2-3-4 and 5 recommend energy procedures for energy audits of the buildings considering the whole building system [14e18].

It must be noted that the enactment of Italian energy measures, regulations and the gradual restriction of minimum energy requirements has substantially contributed to reduced energy consumption in the residential sector since 2011, and, according to the Italian Energy Efficiency Action Plan (NEAAP) [19], in 2020, the expected primary energy saving amounts to 5.14 Mtoe/y from the residential sector.

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However, to date, old buildings and, in general, all buildings located in historical city centres, are excluded from achievement of minimum energy requirements after the application of energy retrofit actions [20,21].

In addition, for residential buildings, the retrofit action application is expensive, voluntary and coming from sporadic decision, causing considerable energy consumption. Therefore, energy refurbishment of historical building seems a very difficult challenge, taking into account the matching among regulations, technical, energy and economic feasibilities.

In this regard, an overview of the interaction process and thematic areas is shown in the flowchart of Fig. 1.

In Fig. 1, the identified energy retrofit areas are shown in the green and orange squares. More in detail, actions are diversified according to difficulties of application of each one, i.e., it can be easier to improve the energy efficiency of the lighting system or the HVAC/DHW system than the envelope or the renewable energy sources (RES) and Thermal Energy Storage technologies exploitation.

Therefore, the choice of an adequate retrofit action is a function of the actual technical standard and the private/public users' expectation. In this end, as reported in the flowchart, building simulations and monitoring, occupant surveys [22] and other analytical tools have a key role in determining the thermophysical and energy characteristics of a building, and simultaneously in assessing the whole feasibility/applicability of the retrofit, also considering the large number of parameters influencing a building's energy performance [23].

This paper aims to analyse the state of art of European and Italian energy retrofit feasibility and application on historical buildings, paying particular attention to energy saving potentialities and issues, to highlight the possibilities for the application of targeted retrofit actions as a source of national energy savings and building reuse improvement.

The proposed methodology is developed by highlighting issues and advantages, area-by-area (Envelope, heating and cooling system, natural ventilation, occupant behaviour, building smart strategies, Renewable Energy Sources and Energy storage), concern the Italian historical building retrofit and related energy saving opportunity.

In the following sections, several European and Italian approaches to building energy classification, technical standards and energy retrofit actions are analysed, focusing on possible application. Moreover, a detailed analysis of residential historical building distribution around Italy and a literature review have been done.

Finally, to help skilledpeople and public administrations inchoosing the retrofit best energy practices, the authors propose a synoptic table that collects international and Italian energy solutions and approaches, by highlighting advantage and disadvantages concerning each application on historical buildings per thematic area.

2. Energy efficiency in historical buildings: some experiences

Since 1991, the Italian Standards and Regulations are focused on the energy refurbishment of existing buildings, but currently there is a serious gap between the actual energy performance of historical building conditions and the energy efficiency actions really applicable to them.

Today, recent Italian energy policy [24] encourages Public Administrations and private citizens to apply some retrofit actions by tax breaks and/or co-funding them by providing ∨ 900 million. However, once again funding measures are mainly addressed to modern buildings/plant systems.

In this respect, it must be noted that the entire Italian residential stock amounts to 11,226,595 with an average useful surface of approximately 96 m^2, while 1,2000,000 residential buildings are considered "historical" [12].

Buratti et al. [25] analysed the state of the art of energy certification of households in an Italian region and compared results with national and international indicators, making it possible to evaluate actual energy performances and savings. Focusing on the age of buildings, the results showed that just 6.0% of buildings built before 1950 are provided an energy certificate, and this building stock has the highest energy consumption. Along this line, it is worth noting that the energy classification, in Italy, has been updated by the government in October 2015 [26,27] and, once again, in this updating, historical buildings are not included in the strict requirements enacted for all other buildings.

As affirmed by Andaloro et al. [28], a key point has been established by building energy certification. The authors have compared the degree of adoption and implementation of EPBD measures among European countries and have analysed four parameters. These are the calculation of the methodology of building energy performances, requirements of energy certificate advisors, adopted energy scale and harmonization with CEN requirements. Furthermore, the authors declared that, despite having suitable energy calculation methods, practical results were significantly different for each country, also because building stock varies country by country.

In the same way, Garcìa Casals [29] has highlighted the limitation of EU energy regulation and the degree of adoption by European countries. As affirmed by the authors, there were many

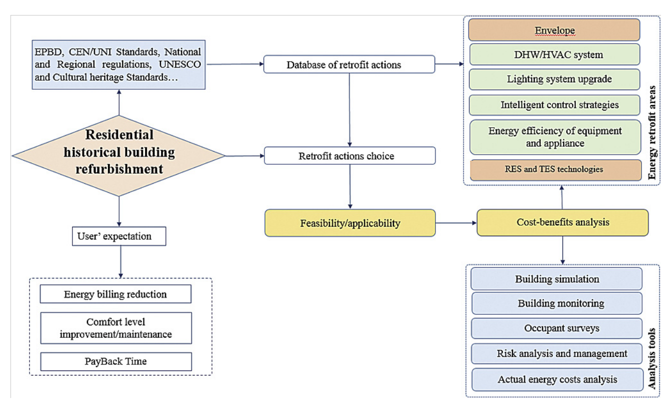

Fig. 1. Flowchart: energy refurbishment design of residential historical building.

difficult-to-accept and difficult-to-adopt new energy assessment tools by architects and public administrators. Nevertheless, many international projects have been developed to improve energy management strategies, e.g., in the framework of the European Projects LIFEþ program or FACTOR20 project [30,31], several energy retrofit measures in residential buildings and in historical city centres [32] have been suggested at the urban level (building and street lighting) despite the historical value restrictions.

In this regard, AiCARR Guidelines "Energy Efficiency in Historic Buildings" [33] proposes the concept of "improvement" of the current energy requirements, also with regard to occupant safety and comfort. De Santoli [34] has highlighted some needs/shortcomings in the definition of energy requirements of historical buildings. Among these needs was the introduction of a performance index relating to non-renewable primary energy, just one definition of nZEB (Net Zero Energy Building) regardless of the type of building and a definition of exported energy method based on the territorial context.

Other countries have tried to solve this issue, e.g., the UK acting on National English historical heritage by means of National Planning Policy Framework and energy efficiency strategies [35].

The main topics highlighted by UK Guidelines is the poor insulation of the buildings and the low performance coefficient of the central heating systems, which have to maintain an indoor temperature of 20 C in very large spaces.

Furthermore, Bakonyi and Dobszay [36] have highlighted the key-role of window refurbishment in old buildings. Authors have proposed a methodology able to improve the heat balance of windows in the Central-European area, by respecting the historical value of glazing elements. The results showed an overcoming of usual calculation based only on U-value which, as affirmed by authors is not a reliable way to find optimized solution in all cases.

Another study, performed in the Baltic Sea Region (BSR), has been made by Zagorskas et al. [37]. Authors have deeply analysed the energy performance of the outside walls of a multi-flat historic buildings. Also in Denmark energy performance requirements for historic buildings is not mandatory, although the occurrence of high-energy consumption of this kind of buildings.

In Italy, the same issue has been considered, but with regard to building insulation the preservation restrictions on historical buildings make it very difficult to apply this action.

Today, building design and/or refurbishment tends to emphasize the nZEB approach [38e40], especially in Italy, where often entire neighbourhoods or cities are classified as “historical.”

Hence, the questions can be proposed: In a historical urban area, what is the best energy balance between energy demand and supply? Could the Net Zero Energy Building theory be applied on historical buildings or neighbourhoods? Could the historical buildings/district achieve nZEB targets? Beccali et al. [41] analysed weighting factors, country by country, taking into account primary conversion factors, to assess their affection on energy balance and then the development of energy requirements for each country. The authors attempted to verify how nZEB requirements matching could be affected by the choice of their definition and the choice of weighting factor system. The authors identified many difficulties applying refurbishment measures on existing buildings in achieving Net Zero targets. In this end, Oliveira Panaoa et al.~ [42] have proposed an assessment method able to define nZEB existing building requirements in the Mediterranean area, hence to give a first energy threshold for the primary energy target in nZEB housing, classifying age and housing use. Obviously, nZEB performance levels can be determined with reasonable calculation effort without the use of an iterative approach or optimization algorithm [43]. For example, in Portugal, the first step of the study starts from “before 1960”, including all typology materials of buildings. However, taking into account the context, the method is useful and replicable in other countries. The authors have developed an analysis based on an actual study case and a simulated one (carried out from national statistical data), by means of DesignBuilder software [44]. In all analysed cases, an inadequate U-value of envelope and a low energy performance of HVAC and DHW systems were found. The results demonstrated a considerable gap between theoretical calculations and actual cases. As affirmed by the authors, this result is justified by the fact that dynamic simulation is independent of the seasonal thermal requirement. Concerning building age categorization, it must be noted that, in the literature there are many different age typologies and classifications. In Italy, 30% of buildings were built before 1945, and 18.3% were built between the years 1919 and 1945. Once again, this fact involves a strong dichotomy between aesthetic-architectonical value and energy efficiency goals.

In this way, Fabbri [45] highlighted qualitative and quantitative issues related to protected buildings, indoor quality conditions, thermo-physical peculiarities, HVAC system integration and primary energy demand. As expected, in historical building refurbishment it is possible to not respect minimum standard requirements. The author affirmed that energy consumption is a function of four factors: building use, occupation rate, building envelope type and heating/cooling system performance. Furthermore, energy consumption, per threshold periods, has been classified, and in this case, building energy consumption mostly derives from buildings built before 1919.

In this context, a detailed study has been made by Ciulla et al. [46]; the authors have simulated a typical residential historical building in different Italian climate zones and have estimated energy saving by applying targeted retrofit actions and related economic investments. Furthermore, a classification of retrofit action priority was proposed. Once again, the authors found a possibility to apply retrofit actions on historical buildings by suggesting caseby-case the best economic and energy solution. It must be noted that, as reported by Desogus et al. [47] in a study performed on building samples built in 1950 in Cagliari, the best energy retrofit practices can also be strongly impeded by economic costs.

In this framework, increasingly widespread studies about heating/cooling urban districts [48] or building smart grid [49,50], able to control power consumption and significantly reduce energy needs by using different energy conservation measures must be cited.

Many authors are showing very interesting results in terms of the energy feasibility and cost-effectiveness of different alternatives [51,52].

In the following section, the Italian historical residential building panorama is analysed through data, some scientific experiences, according to climate context and related energy requirements.

3. Italian climate context and historical residential building stock

Italian architectural heritage is unique in the world and belongs to the period from the Xth to the XXIth century. More in detail, 2,147,400 residential buildings were built before 1919 and are listed as historical buildings [53e55]. Generally, these residential buildings are characterized by a massive thermal envelope with specific properties: permeability, sorptivity, mechanical properties and thermal conductivity, which need to be determined [56]. Following traditional and territorial construction technologies, these constructions are composed of local stones or brick and mortar with considerable thickness. Originally, floors and ceilings were constructed by double wood warping, and sometimes provided by canes vaults with support of stone and mortar. It must be noted that Italian territory was subjected to many earthquakes and much rebuilding of entire cities applying different technologies, while from 1910 to 1940, slab with warped steel was spread.

Often, these buildings are characterized by underground spaces and a ground-floor intended for gigs or carriages, while the floors were usually composed of sequential rooms. The windows were set by wood frame and could be of different sizes depending on the building typology (noble floor, secondary floor, etc.). The heating system, where present, consisted of a heater or fireplace, while modern heating/cooling and DHW systems were progressively introduced [57].

Therefore, as is well-known, these kinds of buildings have different thermal behaviour from modern ones due to their very massive walls and the climate zone in which they are located.

These typologies are diffused over all Italian territory but their energy performances are different relative to the climate zones. There are areas of the Italian territory that (theoretically) have the same climate, so it is possible to suppose identical or similar conditions.

The Italian Standards are based on ideal heating energy demand (operating for 24 h) and a heating turning on/off system depending on the Climate Zone [58]. In particular, based on the heating degree days (HDD), it is possible to identify six different Climate Zones: from A (the hottest zone) to F (the coolest zone) and for each zone, the daily hours for turning-on the heating system and the period are determined [59]. In this end, the main data are collected in Table 1.

Moreover, a matching data between ISTAT [53e55] and ENEA databases [60] has been done, in order to identify Municipalities distribution per Climate Zone and relating historical residential buildings occurrence. In Italy, there are 8047 Municipalities and 70% of these belong to D and E Climate Zones; the last one includes the most part of Municipalities and of historical residential buildings, as better specified in Fig. 2 and Table 2. In detail, Fig. 2 shows the distribution of only the buildings built before 1919 around the Italian Climate Zones and this stock represents the sample of the representative Italian historical buildings.

To improve the energy performance of these building stocks, in the literature it is possible to find several energy measures, scientific approaches and experiences acting on the thermal envelope, HVAC system, user behaviour, global indoor comfort improvement and possible RES applications.

To have an organized overview of the above-mentioned areas of intervention, in the following sections the authors discuss the main literature examples, highlighting the feasibility of retrofit actions on the buildings and the neighbourhoods.

4. Feasibility of energy retrofit actions on historical buildings

The increasing interest in the energy facet of Italian residential building stock encourages many Italian research projects. Thus, a very interesting project called "TABULA" was developed by TEBE research group from 2013, in the framework of the EPISCOPE project (Energy Performance Indicator Tracking Schemes for the Continuous Optimization of Refurbishment Processes in European Housing Stocks) [61]. The authors divided the Italian residential building stock in eight Building Age Classes, and presented a methodology for the identification of reference buildings aimed at creating a tool for European Building typologies [62,63]. However, even if this method is applicable to many classes, it is not useful for Classes including buildings built before 1900 and from 1901 to 1920, because thermal loss reduction is usually achieved by a strong action on envelope. Hence, also in this case, energy retrofit applications must be evaluated case-by-case. It must be highlighted that in any case, an urban energy map results in a very efficacious strategy, especially when it is applied on urban areas developed before the Second World War.

In this end, Ascione et al. [64] proposed a method to optimize energy generation and use in the historical centre of Benevento (Italy). The proposed methodology focused on heating, cooling and electrical energy demand of buildings applied on different levels

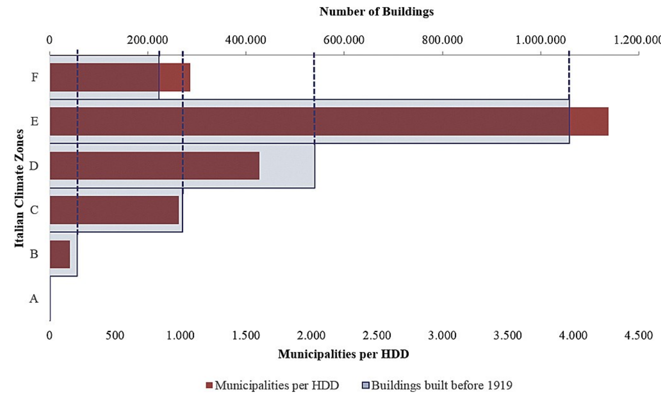

Fig. 2. Historical residential buildings and Municipalities distribution per Climate Zone.

Table 2
Municipalities and historical buildings percentage distribution.

	A	B	C	D	E	F
Municipalities per HDD	0.02%	1.94%	12.19%	19.80%	52.77%	13.28%
Buildings built before 1919	0.01%	2.59%	12.60%	25.13%	49.26%	10.40%

(from building to neighbourhoods). The authors have analysed the energy performance of more than 500 buildings, using standard weather data [65] and GIS tools [66]. Along this line, the authors have characterized the distribution of seasonal energy demand. Furthermore, they have applied a polygeneration system coupled to building-plant systems to reduce the global primary energy consumption. The results showed that an urban energy map is the most useful tool for identifying energy building typologies, and showed which best practices are applicable.

Similarly, Fumo et al. [67] have approached the estimation of building energy consumption through dynamic simulation and fuel bill information to obtain a detailed hourly estimation of building electrical and fuel demands. Meanwhile, to facilitate an understanding of the just mentioned issues for lay people, Asadi et al. [68] developed in 2012 a simple estimation tool able to predict thermal and economic performances of some actions and to make the occupant "energy-conscious".

In the same framework, Caputo et al. [69] have developed a methodology defining and characterizing the energy demand of buildings and entire urban areas by means of 56 building archetype definitions in Milan. Results have shown the effect of improved energy efficiency (building envelope and heating system) on energy policy, also compared to those in the SIRENA database [70] stressing the attention to detailed knowledge consumption and performance of the energy districts.

Table 1
Italian Climate Zones and corresponding HHD according to DPR412/93.

Climate zone	HDD	Heating season	Operating hours	Number of cities
A	600	From 1st dec to 15th mar	6	2
B	601e900	From 1st dec to 31th mar	8	157
C	901e1400	From 15th nov to 31th mar	10	989
D	1401e2100	From 1st nov to 15th apr	12	1611
E	2101e3000	From 15th oct to 15th apr	14	4271
F	3001	From 5th oct to 22th apr	No limitations	1071

The same methodological approach has been followed by Horta et al. [71], applying a quantitative methodology to evaluate residential building energy performance at a municipal level in Portugal.

To determine the best energy practices to use in a retrofit phase, in the following sections are collected the more diffuse International and Italian retrofit measures applicable to Italian historical buildings. Some collected energy measures refer to public and/or modern buildings, but the authors think they are also easily applied to historical buildings.

4.1. Envelope

A detailed envelope knowledge (opaque and transparent) is fundamental to identifying thermal heat flow, thermal inertia, insulation level and proper retrofit actions [72]. Generally, in Italy, before 1976, all insulation occurred on buildings. A literature review showed how the envelope quality is a crucial point in all refurbishment actions [73]. In detail, historical brick walls require detailed analysis of U-value [W/m^{2}K], hydrophobic properties, etc. Furthermore, several aspects of refurbishment action must be taken into account: durability of intervention, impact on energy demand for heating and cooling, fire safety, aesthetic quality, impact on cultural heritage, maintenance, etc. To this end, several thermal insulation materials and technical solutions have been proposed [74e76]. The current eligible best practices take into account the insulation proprieties of several plasters, today available on the construction market for external application, while very few studies are focused on interior insulation of walls. This kind of materials guarantees the breathability in the building, improving indoor safety and air quality. Indeed, insulating plaster can be a very useful tool not only for protecting walls but also for significantly improving the energy efficiency of buildings.

Bianco et al. [77] have tested a new thermal insulating plaster in Turin. This plaster has been produced by adding to the natural vegetal aggregate materials derived from corn production waste. The authors have monitored building behaviour through measurements on the vertical envelope of the heat flux, internal and external surface temperatures and air temperature. The results, carried out with laboratory measurement and a monitoring campaign, have shown a thermal heat flow reduction across the wall of approximately 20e40%. That the hygro-thermal behaviour wall provided interior insulation is well-known [78]. Nevertheless, where it is not possible to apply external material solutions on walls, internal envelope actions could be carefully considered.

Along this line, a laboratory setup conducted by Johansson et al. [79,80] demonstrated the suitability of Vacuum Insulation Panels (VIPs) applications. The authors have analysed four brick and six mortar typologies by using numerical simulations. Furthermore, the authors tested the material impact in a climatic chamber, comparing wall performances with and without interior VIPs, measured relative humidity in thermal bridges, and performed hygro-thermal numerical simulation and measurements. The results showed that interior insulation significantly reduced the wall temperature, while increasing RH from approximately 60%e100%, causing condensing phenomena. However, the authors affirmed that the proper thickness of VIPs surrounding thermal break areas can reduce RH increase, preserve wall quality, while a small reduction of energy saving occurs.

On the other hand, a very interesting proposal has been made by Italian authors [81,82] in 2014. Indeed, after the 2009 earthquake in the Abruzzo region, entire reconstruction of many historical centres was necessary, carefully preserving historical heritage. To this end, the authors have analysed and classified masonry typologies and have proposed different levels of intervention (from low to high transformability). By means of a “case-by-case” methodology, several types of insulation have been proposed and the corresponding energy performance has been evaluated. The results have showed that in some cases, a 50% of energy saving has been achieved.

As mentioned above, a targeted action, especially in wall insulation retrofit, is the best way to limit thermal losses, and in this regard climate plays a key role. Indeed, as studied by Baglivo and Congedo [83] a multi-criteria analysis could be a useful statistical approach to characterizing and optimizing opaque and transparent building envelopes. Therefore, the authors proposed a tool, based on previous studies [84,85], that by means of square symmetrical matrixes, demonstrated the achievement of high performance by thin and ultra-thin walls in a cold climate, and also analysed acoustic and hygrometric parameters.

On the other hand, Li and Malkawi [86] have applied a multiobjective optimization to predict and control building envelope thermal mass to shift cooling load and reduce energy and economic costs; in this manner a saving of approximately 50% has been demonstrated.

4.2. Heating/cooling system, natural ventilation and occupant behaviour

Heating, ventilation and air-conditioning systems represent the largest energy end use in both the residential and non-residential sector. As affirmed by Perez-Lombard et al. [87], to guarantee indoor thermal comfort, air-conditioning energy consumption accounts for almost half the energy consumed in buildings, and approximately 10e20% of total energy consumption in developed countries. In addition, historical buildings usually show high average heating needs and high energy billing due to several architectural characteristics and legal limits of intervention. Obviously, this fact does not make easy application of efficient energy saving actions. However, many solutions could be adopted respecting the historical value of the building.

Ascione et al. suggests several cheap actions that significantly reduced primary energy consumption [88]. The study was performed on the “Palazzo dell'Aquila Bosco-Lucarelli” located in Benevento (South-Italy) and is used by the University of Sannio. Even if this study had been applied on a public building, most of the proposed actions are replicable on residential buildings. In detail, the authors suggested modifying indoor temperature set-points from 22 C to 20 C in the winter season, and from 24 C to 26 C in the summer season. The results showed that important economical and energy savings can be achieved. Furthermore, the authors proposed other energy saving actions, such as installation of a control valve on each fan-coil, installation of zone thermostats, etc.

Celenza et al. [89] highlighted in a theoretical study how a heating account can be an efficient user's know-how tool to reduce energy consumption. Indeed, energy billing is based on actual heating, air-conditioning and DHW production economical costs. Therefore, thermal and electrical energy measurement devices can be considered effective tools for enhancing energy efficiency and improving energy savings. The authors have verified that, generally, in historical buildings heating systems are composed of central heating plants with vertical distribution, involving a very difficult distribution of heating cost due to complicated or unfeasible architectonical modification. For this reason, the authors applied an easy and low-cost heating accounting system with thermostatic radiator valves (THV) to set and control proper indoor temperature room by room. Furthermore, the authors have analysed several indirect accounting systems such as heat cost allocators, time counters, and time counters compensated with HDD.

Another interesting study has been performed by Homod et al. [90], in which the authors studied the effect on energy saving through integrating control on both HVAC systems and natural ventilation. In detail, the authors recognized factors affecting indoor air temperature, taking into account the indoor comfort of the occupants in a tropical climate. The results show that the most affecting factor increasing energy consumption is the cooling system. Indeed, it continuously operates even at low outdoor temperatures to guarantee thermal comfort and overcome indoor loads. Simulations have demonstrated that indoor predicted mean vote (PMV) is increased by natural ventilation and energy saving is 31.6% less than in a typical HVAC system. It must be noted that during the last two decades, improvement of appliances into the hosing contributes to increased internal loads, so a proper natural ventilation for passive cooling is necessary. Nevertheless, in a naturally ventilated building, air speed should be controlled to satisfy the occupants' indoor comfort, because, as studied by Etheridge et al. [91], airflow rates constantly vary with the weather.

Gratia et al. [92] have analysed the effect of natural ventilation on cooling and heating load by comparing different building orientations, wind directions and window sizes and positions. The results have shown that several strategies are adoptable to favour the cross ventilation and then the free-cooling. These strategies include means of single-side day ventilation in which cooling needs are reduced by 30%.

Certainly, these solutions can be easily applied in the area of Southern Italy, where high air temperatures occur throughout much of the year.

4.3. Intelligent control strategies and global indoor comfort

The European Standard EN 15232 [93] put into evidence the key role of Building Automation Control Systems (BACS) and Technical Building Management (TBM) systems. Along this line, proper building system control is an efficient choice for energy demand and maintenance cost decrease, also guaranteeing indoor comfort [94,95]. Indeed, the actual room occupation analysis and its control, in working and domestic spaces, is a very suitable strategy to reduce thermal and electrical energy demand. This EU Standard provides a list of BACS and TBM functions that can affect the energy performance of buildings and introduces a classification of different BAC efficiency classes, based on the control level for the users.

In this framework, the potential for energy savings lies in the control and interaction of heating/cooling systems, appliances and electric devices to reach their full efficiency during operating hours, thanks to the recourse of specific software systems that orchestrate all energy facilities in the house [96,97].

In this way, Caicedo and Pandharipande [98] tested in an office room a multi-hour optimization method taking into account the effect of an actual hour control variable to predict energy consumption in subsequent hours. The authors used a non-linear optimization model, extracting equations that provide accurate and fast solution, that can solve optimization issues for five different occupied zones. Hence, by considering internal and solar gains, heat transfer, ventilation rate, conditioning system load and daylight, the authors demonstrated that multi-hour integrated control considerably increases energy saving with respect to traditional schedule control.

In 2014, Aria and Akbari [99] applied the same methodology to develop a new control system model. The authors considered the thermal effect of individual zones by means of two objective control functions of shade based on illuminance. The results showed that a yearly energy saving of approximately 35% was achieved. These kinds of solutions are easily applicable in working spaces, because time and occupation are generally known and/or predictable, while a different approach has to be adopted for domestic spaces. In fact, in residential zones, it is more challenging to predict energy end-uses, especially if the case study is an urban zone or historical centre. In Italy, the emptying phenomena of these places makes very difficult the analysis of thermal and electrical consumption modelling.

To this end, a statistical approach, by means of modelling data and billing cost, has been studied by Ben and Steemers [100]. The study has been conducted in the UK and it has been applied on the Brunswick Centre in London. Particularly, the authors have analysed the effect of behavioural variables on energy saving using these inputs: building and occupancy data, actual energy use data and behavioural change physical improvement. It must be noted that occupant behaviour is the most important variable for energy saving achievement. The authors have conducted several retrofit action levels and one of these is the characterization of the user's routine. They have classified three levels: low-energy, mediumenergy, and high-energy behaviour based on a more or less "reasonable" heating set-point temperature zone by zone. Particularly, the heating schedule has been set at 21 C in the living room, while the set-point temperatures into the other rooms were 18 C. The hypothesized time schedule was: from 07:00 a.m. to 09:00 a.m. and from 04:00 p.m. to 11:00 p.m. in the weekdays, and from 07:00 a.m. to 11:00 p.m. in the weekends. The minimum set-point temperature for the whole flat was 15 C. The results showed that the behavioural effect (high-e to low-e) on energy saving varies from 62% (low-energy behaviour) to 86% (high-energy behaviour). This theoretical study demonstrated that proper occupant behaviour is one of the most efficient ways to save energy.

In this way, it can be affirmed that a balance between indoor comfort and related energy consumption must be studied. Obviously, proper use of survey tools [101] or adequate thermohygrometric/daylighting performance indices [102,103] could be useful to identify the best energy measures. Indeed, proper choice of glass replacement and shading use contribute to improved visual comfort conditions and radiation load reduction and control [104,105].

Harmathy et al. [106] have developed a multi-criterion analysis for building envelope optimization taking into account global comfort and energy saving. The authors demonstrated that electric energy saving due to artificial lighting could be reduced of approximately 70%, at the same time guaranteeing occupant visual comfort. A multitude of studies is focused on the impact of solar shading system installation, which is very easy to apply in a particular context such as old buildings, evaluating energy, economic and comfort results. Chaiwiwatworakul et al. [107] demonstrated that by using this system it possible to achieve an energy savings of up to 80%, while improving indoor visual conditions.

As in other instances, there is no single way to achieve the energy-economic aim, indeed in any case everyone/combination of some of them should be evaluated case-by-case. Finally, in the following section, RES installation issues are reported and specifically, some Italian scientific proposals about RES installation on historical buildings are described.

4.4. Renewable energy sources and energy storage

Distributed energy generation is worldwide studied [108e110] and its advantages and issues have been highlighted especially in trying to make self-energy autonomous buildings and urban centres [111,112].

In Italy, the hardest challenge in building energy actions is the installation of RES, such as PV systems or solar collectors, on historical building roofs. Nevertheless, many researchers and local administrations are involved in this field to solve issues of electrical and thermal energy production on-site [113e115]. It is clear that a proper energy policy, permitting an integrated photovoltaic and thermal (BIPVT) system, could be the best opportunity for distributed clean energy generation in the urban environment [116e118], also taking into account the faster and faster development and market availability of high-performance technologies [119,120].

Bellia et al. [121] have proposed a particular PV system installation on historical buildings in Naples. In fact, the authors have two solutions of PV modules. The first one is a module permitting to respect architectural limits, waterproofing needs and daylight comfort improvement. Indeed, PV panel is half-transparent, but indoor overheating occurs after its installation. For this reason, an opaque PV module installation has been considered. However, the authors have developed a multidisciplinary approach to exanimate building, concluding that only a complete and diversified action on a building can improve its energy efficiency.

On the other hand, the issue of integration of solar technologies in historical buildings of the Mediterranean area has been enhanced by Moschella et al. in Catania [122]. The authors have analysed the current scenario of integrated solar technologies, paying particular attention to building-integrated photovoltaic (BIPV) systems and building-integrated solar thermal (BIST) application on the envelope. However, in this framework, the important shadowing effect, which occurs in historical centres, must be considered. The authors have proposed a set of retrofit actions such as the application of a hybrid system BIPV/T on a typical historical building representative of the city of Catania. The authors have advised installation of a BIPV/T system on the building façade (without particular historical value) or on the roof and a solution with thin film application. Furthermore, they have proposed replacing the current glass with PV glass on other buildings. The authors demonstrated that RES could be easily applied on historical buildings, but actual implementation of these retrofit actions is more difficult due to the inevitable modification of most of the protected buildings.

On the other hand, many researchers are involved in Thermal Energy Storage (TES) development for residential use that appears very promising in building energy saving in both energy selfproducing and waste heat [123]. According to Pilkington Solar International GmbH [124], TES can be classified basing on storage technology: latent, sensible and chemical and concept: passive or active [125,126].

Despite this technology has a great disadvantage due to the large discrepancy between the supply and the demand [127], as

Table 3
Synoptic table of citation per energy action area.

Retrofit action		International citations	Italian citations	Advantages	Disadvantages
Wall insulation	Internal	Zagorskas [37]; Jelle [75]; Johansson [79,80]	Bianco [77]; Guizzardi [78]	Façade preservation; energy saving	Condensing issues; internal space decrease; no-effect on thermal bridge; high PBTs
	External	H€akkinen [74]	Desogus [47]	Thermal bridge issue solution; energy saving	Not always applicable; high PBTs
	Both	Roberts [73]; Garas [76]	De Berardinis [81]	Thermal bridge issue solution; energy saving	Not always applicable; high PBTs
Whole envelope insulation	Wall/roof/window	Bakonyi and Dobszay [36]; Asadi [68]; Wang [72];	Ascione [88]	Noticeable energy saving	Not always applicable
HVAC	THV	Gratia [92]	Dalla Mora [38]; Celenza [89]	Thermal comfort maintenance; energy saving	To adapt the actual plant to the installation of THV
Combined actions Building-plant system		Tadeu [40]	Beccali [30]; Ardente. [39]; Franco [57]; Ciampi [82]; Ciulla [46]; Di Pilla [132]	Noticeable energy saving	Not always applicable; high PBTs
Intelligent Control strategies/human factor		Homod [90]; Caicedo [98]; Aria [99]; Ben [100]; Chaiwiwatworakul [107]	Pisello [94]; Ippolito [95]; Beccali [96]	Noticeable electrical energy saving	High PBTs
RES and TES		Ruhang [108]; Zhang [109]; Zhang [110]; Milan [112]; Polo Lopez [115]; Zhai [123]; Li [125]; Li [126]; Esen [127e129]; Khadiran [131].	Rotilio [113]; Bonomo [114]; Leone [116]; Bellia [121]; Moschella [122]	Thermal and electrical energy production (great potentiality)	RES: Restrictions on Italian historical centers; TES: further development of technology need

theoretically demonstrated by Esen et al. [128,129] it appear as a good technical solution to be couple to heat pumps.

Indeed, there are several technologies able to be coupled with HVAC systems and RES. In this end, Li [130] recognized factors affecting energy and exergy performances of this kind of system: fluid mass flow rate, tank geometrical structure, fluid properties and fluid temperature.

However to date, experimental studies are focused on materials properties of the system, paying particular attention to Phase Change Materials (PCM) application [131].

Overcoming restrictions about RES installation in historical centres and development of TES technologies could be a powerful way to easily achieve national energy sustainability.

5. Discussion

As mentioned above, it is possible to use different approaches in historical building refurbishment, despite the standard restrictions. In this manner, authors have collected several experiences and studies to aid the choice of the proper energy retrofit action.

In this regard, it must be cited other similar studies that have approached the issue of energy retrofit by different points-of-views as follows: review of energy calculation methods for commercial buildings [132]; energy classification and energy performance diagnosis [133]; building retrofit technologies state-of-the-art [134]; wall composing historical buildings [135] and state-of-theart of green roof technologies upgrading and expected energy saving [136].

However, results showed in this paper give a wide overview on suitable solutions for the specific issue concerns historical building energy retrofit by progressing area-by-area.

Indeed, the current trend to re-inhabiting and reusing Italian historical centres involves a focused approach on energy consumption management. To this end, in the synoptic Table 3, the previously discussed literature experiences are collected and advantages and disadvantages of each retrofit action are provided. Furthermore, a subdivision between international and Italian scientific works has been done to highlight how Italian researchers approach the debate and try to solve this problem.

Accordingly, the most difficult energy retrofit action is the improvement of the envelope insulation. This action must be considered "case by case" due to limits of intervention on façades, while a suitable solution could be the internal insulation, where possible, taking into account condensing phenomena; a noticeable reduction of primary energy demand is due to replacement of windows. The improvement of energy efficiency on an HVAC system results easily where central heating occurs by using an account-heating system. The smart control of lighting and conditioning systems is developing as one of the most useful energy saving strategies applicable on buildings.

About RES, although some Italian authors proposed such strong actions, to date their installations on historical centres remains the main problem to solve for really improving the energy sustainability of the cities as in other countries.

Anyway, the payback time (PBT) of a single or combination of actions is a key factor in application of each action in residential housing. Indeed, the retrofit action often includes high costs for owners, poor energy benefits and high PBTs. As demonstrated by Ciulla et al. [46], PBTs vary for the same energy measure from colder to warmer zones. Along this line, a clear proof has been provided by Di Pilla et al. [137]. The authors demonstrated how energy-financial plans could be a powerful and strategic way through the investigation of future incentive policies and, underlining the ineffective retrofit actions in some areas, showed that the government should plan and encourage owners to apply energy conservation measures in historical housing.

6. Conclusions

In Italy, historical building retrofitting is a challenge for researchers/architects and administrators. Indeed, the conservation and rehabilitation of historical centres can also improve the energy aspects and the quality of life in local communities.

To improve the energy performance of the actual building heritage, there are several studies that analyse the feasibility of different actions that follow regulatory restrictions. The proposed work is state of the art in the main Italian and international literature. The most significant actions are improvement of the building envelope insulation and the HVAC/DHW systems, while RES and TES integration is difficult.

Therefore, implementation of the discussed actions is not always viable, nor are they the only solution. Moreover, this work is a collection of observations to be used for further information and studies in the field, facilitating the reader in research and comparison. Obviously, a complete analysis is based on the simultaneous evaluation of the economic feasibility and the determination of the related payback time that often discourages owners from taking retrofit actions.

Furthermore, a powerful impetus should be made by the Italian government, by means of a proper energy policy, to regulate the “energy status” of this sector and the application of some cited actions, to promote energy saving strategies, to reduce energy consumption and to preserve the historical value of buildings and centres.

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