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Energy and economic analysis on retrofit actions for Italian public historic buildings

R. Ricciu [a*], A. Galatioto [a,], T. Salem [b], E. Kinab [c]

[a] DICAAR - Dipartimento di Ingegneria Civile, Ambientale e Architettura, Universita degli Studi di Cagliari, Cagliari, Italy [b] Department of Civil and Environmental Engineering, Notre Dame University-Louaize, Zouk Mosbeh, Lebanon [c] Lebanese University, Faculty of Engineering, Roumieh, Lebanon

https://doi.org/10.1016/j.energy.2019.03.167

According to the recent EU Directives on building energy efficiency, the Italian government is paying particular attention to energy refurbishments of buildings by enacting energy measures and obtaining significant results.

In particular, the Italian government is providing economic incentives to citizens or public administrations that improve the envelope of the energy performance of a building. However, according to strict national regulations concerning building heritage, most actions cannot be applied to historic buildings, even though they represent approximately 30.1% of all buildings. In this context, the energy retrofits for Italian buildings are not simple but necessary. Therefore, in this work, a public historic building was simulated, and some permitted retrofit actions were applied to analyse the effectiveness of national measures in four different climatic zones. The results showed that the same applied action that reduces the primary energy consumption in some zones will significantly increase consumption in other zones, even if the zones fall within the same case-law. Finally, the results highlight two main unsolved issues: the renewable energy source installation of a historic building and a strong distinction between measures and economic incentives around the Italian peninsula, which has very different climate conditions. © 2019 Elsevier Ltd. All rights reserved.

Keywords:
Energy retrofit
Historic building
Energy policy
Payback time
Economic feasibility

a b s t r a c t

1. Introduction

In Europe, the greatest potential for energy saving lies in the existing building sector, which is responsible for approximately 40% of the global primary energy demand [1,2]. According to IEA studies [3], although many countries have implemented a national energy policy to improve building energy performance, the mean energy consumption per citizen still remains unchanged since 1990. It has been well-known for many years that the European energy policy encourages energy retrofit measures to be applied to this area [4e8] and that energy savings and CO_2 emission reduction goals have already been achieved [9,10]. In this context, it must be noted that among European countries, different energy strategies have been adopted with respect to community legislation.

A keystone of this action is a general comfort maintenance for housing that is contrary to the “fuel-poverty” that is responsible for household indebtedness as stated by the Paris Agreement implementation [11], i.e., the French government promoted energy actions based on housing policy, urban and ecological regeneration to reduce CO2 emissions and cause more efficient energy use. In fact, one of the goals of the government is to renovate 500,000 dwellings per year and targets the renovation of low-income households. To favour energy efficient improvement, some approaches have been suggested by researchers, i.e., a public-private partnership with a strong participation from the local authorities that must have a proper knowledge of the status, occupation level and energy consumption of their buildings [12] or by considering the new lowenergy individual houses in France [13].

The United Kingdom successfully reduced its GHG emissions by 25%, from 1970 to 2010 [14]. Indeed, its national energy policy provides several

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* Corresponding author.

E-mail addresses: ricciu@unica.it (R. Ricciu), alessandra.galatioto@unica.it (A. Galatioto), tsalem@ndu.edu.lb (T. Salem), elias.kinab@ul.edu.lb (E. Kinab).

incentive mechanisms in order to improve energy measures in different fields, i.e., a “feed-in tariff” (FIT) [15]. This programme can accelerate investments in renewable energy technologies by offering long-term contracts to renewable energy producers and is typically based on the cost of generation of each technology. The goal is to offer cost-based compensation to producers and to favour the long-term contracts that encourage renewable energy finance investments. Other energy measures are focused on building stock refurbishments by the Domestic Renewable Heat Incentive (DRHI) enactment [16]. Actually, in the UK, this field is a priority due to building stock age (approximately 75% of residential buildings were built before 1985 with poor energy performance) and historic buildings (built before 1919), where it is difficult to improve the energy efficiency due to UK legislation [17] and to achieve the goal of the Climate Change Act [18]. In reality, as reported by Ginks and Painter [19] in the UK, any alteration to a protected building requires consent from the local authority, including alterations to the building envelope. Additionally, a proper methodology and guidelines on the application of energy retrofit measures has restricted the development of energy efficiency in historic buildings.

In addition, the German government has ambitious goals regarding GHG reduction (40% by 2020 and by 80% by 2050 in comparison with 1990) [20]; to achieve this goal, the Kreditanstalt für Wiederaufbau low lending rates (1e2% in 2012) were offered in 2013, electric energy storage installation was encouraged and in 2014, and 5640 systems have been financed. However, several issues have been highlighted in this action, i.e., 20 years duration of incentives, the high payback times, and a high complexity of the procedures [21].

Furthermore, in the energy retrofit of buildings, much work must yet been done to truly make the existing buildings energy efficient to achieve the European net Zero Energy Building (nZEB) targets [22,23].

For example, 30.1% of Italian buildings were built before World War II [24], and, in 2004, the Italian government adopted a law that classifies the buildings older than 50 years as “protected” [25]. Hence, if several energy strategies and policies are to be implemented, it will be very difficult to achieve the 2020 goals considering the complex work needed to apply energy retrofit actions to the historic “protected” condition of 2,150,259 building units in the Italian State [26], of which 13% are office buildings [27].

Regarding the conversion of existing Italian buildings in nZEB [28], ENEA (the Italian National agency for New technologies, Energy and sustainable Economic development) has estimated that the energy consumption for the building sector in Italy amounts to 4.3 TWh/year, resulting in a cost of approximately 644 billion V/year for the public administration; only 1.3% per year of these expenditures are used for building maintenance. The results of these studies have demonstrated that, in the North of Italy, the annual investment expenses to complete the conversion in nZEB would be approximately 20% of the region’s energy supply cost. For central and southern Italy, on the other hand, the required investments to achieve the same goal defined by nZEB would be double. In any case, a general consideration has been made: the energy refurbishment of a transparent and opaque building envelope cannot always produce economic and energy benefits; thus, careful consideration about where and which retrofit action is suitable case-by-case must be considered. After the recent earthquakes that affected various Italian regions, a census of government-owned buildings by building age was performed. It was confirmed that 30.1% of buildings falls in the “protected status” [29]. Unfortunately, information is only available about the distribution of these buildings by district and Metropolitan area but not by municipalities or by climatic zone.

A typical Italian historic public building has large dimensions and was built principally by using cut stone walls, stone walls in irregular blocks, walls of tuff blocks, and mixed walls of stones and bricks and bricks. Unfortunately, to date, a single or complete database about building heritage in use or in possession of the government does not exist, especially considering the numerous subjects involved (central and local administrations) and related characteristics [30].

For this reason, the topic of the best energy retrofit practices for Italian historic buildings has been studied more and more by researchers who are analysing the impact of energy retrofit actions on historic buildings [31,32], comparing and developing procedures and protocols [33], and studying the effectiveness of recent government energy policies [34,35]. However, these studies are mostly focused on residential buildings, schools, historic city centre restoration, or only a few building case studies.

Furthermore, Castaldo et al. [36], Nardi et al. [37], Manzan et al. [38], Cabeza et al. [39] and Rospi et al. [40] have studied applied energy efficiency measures on listed and historic buildings and have highlighted some crucial points about a) the need for Italy to improve the energy efficiency of historic buildings because it represents a large portion of national energy consumption in buildings; b) how the constraints of the existing regulations for the preservation of the historic value of buildings make energy refurbishment very challenging because the application of passive and active energy strategies are often in contrast with architectural features in most cases, and the best available technologies are not applicable since they are in contrast with the conservation of their historic value; c) the fact that each energy retrofit measure must be tailored to each historic building; d) the passive energy measure of internal insulation seems to be the best solution according to thermophysical characteristics of insulation that can be applied to massive construction, which is typical of these kinds of buildings; and, finally, e) the difficulty in installing Renewable Energy Sources (RES) due to architectural law constraints that are applied often not only on the building but also on the district where they are located.

Therefore, the implementation of effective actions in this field could be a good way to improve the overall national energy efficiency. Thus, as part of a larger project on the suitability of energy actions for the retrofit of historic buildings, the goal of this paper is to analyse and conduct dynamic simulations for several retrofit solutions that can be applied to historic Italian public office buildings, taking into consideration the governmental financing incentives and the different Italian climate zones. As a matter of fact, the results contribute to the best practices to globally reduce energy consumption in this field, to identify energy action priorities zone-by-zone and to highlight current shortcomings and issues in the Italian energy policy.

2. Italian energy policy and incentive tools in building refurbishment

Since 1991, the Italian government has enacted more and more restrictive regulations related to energy consumption. Furthermore, according to the Legislative Decree 192/2005 and the subsequent modifications and implementations [41], a key-goal was achieved in 2009 by the standardization of the building energy certificate for Italian buildings [42,43]. This tool led to a definition of the actual state of the art for energy efficiency in Italian buildings, to the creation of city energy maps, to the elimination of gaps in regulations and to the establishment of national financial incentives aimed at solving energy problems.

Furthermore, a powerful energy shift has been achieved by the “Covenant of Majors” [44] (2100 Italian municipalities) that, by implementing the Sustainable Energy Action Plans (SEAP) [45], have involved local and regional administrations in enhancing energy efficiency at building and urban levels.

In addition, to improve Renewable Energy Source (RES) exploitation, reduce thermal and electric end-uses, and upgrade building energy characteristics, many financial tools have been provided.

Thus, in February 2016, a financial tool costing V 700 million, called “Conto Termico 2”, was enacted by the Italian government [46]. This tool addresses small energy interventions with the principles of simplification, effectiveness, diversification and technological innovation in the renovation of public administrative buildings.

Furthermore, this measure finances the following macro-areas: transparent and opaque building envelope insulation, condensing boiler installation, shading devices in the East-South-East and West orientations, lighting systems replacement, smart control and building automation systems, thermoregulation and heat metre installation, PV systems, and PV/th systems among others.

The GSE “Gestore dei Servizi Energetici” provides the maximum incentive (eventually aggregated) according to the general principle described in Eq. (1).

$$I_{TOT} ¼ 0:4 C \ A_{int}; \qquad I_{TOT} \ I_{max} \qquad (1)$$

where 0.4 is the maximum cumulative incentive (40% of the total cost), C is the specific cost of the intervention [V], A is the area of intervention [m^2], and Imax is the maximum aggregate incentive [V] that varies action-by-action.

The financing period varies on the basis of the intervention type and user (private citizen, public administration or energy service company) as well as the rates that are given over the years, generally between 5 years (i.e., wall insulation) and 2 years (i.e., solar cooling system installation).

Thus, in the following sections, an actual case study is proposed and analysed, in order to know determine the energy and economic performances in different climatic zones and then to verify the effectiveness of the Italian financing policy across the National territory.

3. Case study

An office building situated in Carbonia, Sardinia, is proposed in this paper as a case study for energy and economic performance analysis. Carbonia is located in climatic zone C (922 HDD), however Cagliari weather data (climatic zone C 990 HDD) was adopted for the energy simulations due to the fact that the meteorological weather data file for Carbonia is not available in the international weather database.

The building was studied in the framework of the project “Development of Technological centre of Sulcis: Low carbon technologies and methodologies and Nearly Zero Energy Buildings (nZEB)” [47] financed by the Italian Ministry of Economic Development [48] and ENEA e the Italian National Agency for New Technologies, Energy and Sustainable Economic Development [49] and in cooperation with SOTACARBO s.p.a [50].

This building is considered “historic” because it was built in 1938 and is subject to architectural constraints, and only some energy retrofit actions can be applied. Indeed, as stated by the Italian ministerial decree number 22 in 2004 [25], buildings having important typological characteristics or considered as “nodal points” in historic urban context, ordinary, extraordinary maintenance and conservative refurbishments are allowed with functional technologies renovations only by maintaining the original typological and morphological architectural features. Application of an external thermal coat or any intervention modifying facades is excluded.

Additionally, in 2016, the central heat was replaced with a more efficient reversible heat pump. In fact, it is very common to find that some parts of public historic buildings around the Italian peninsula have been renovated, with improved efficiency HVAC systems like this building, due to their age. Considering the intended use and particular status of the building, and based on a recent literature review, the authors believe that the selected building can be considered a typical Italian public building that requires energy refurbishment [51]. A 3D view of the selected building is shown in Fig. 1.

The occupied area of the building is 2462.60 m^2, and the gross volume is 7984.70 m^3, while the shape factor (S/V) is equal to 0.43.

The building is characterized by a bearing wall made of local stone with internal and external plaster (without insulation). The internal walls are made of hollow brick, and the building has a sloping tile roof. The windows are characterized as follows: aluminium frame (without thermal break) with double clear glazing, and some internal shading devices exist. The average Uvalue of the windows is approximately 5.28 W/m^{2}K. In addition, the artificial lighting system consists of fluorescent lamps. In Table 1, the thermal characteristics of the building envelope are presented, while, in Table 2, the building loss surfaces and the loss surface/ window ratio are reported per orientation.

For the space use, the occupancy scenarios have been determined according to the actual behaviour of the occupants: the building is in use on Monday, Wednesday and Friday from 08:00 a.m. to 14:00 p.m. and on Tuesday and Thursday from 08:00 a.m. to 18:00 p.m. Additionally, holiday periods were considered, and heating-cooling operating standards have been set according to different climate zones [52] as shown in Table 3. Furthermore, as mentioned above, a new electric reversible heat pump of 650 kW was provided by the local administration in 2016. The heat pump has a COP of 3.34 in the heating mode and an EER of 2.83 in the cooling mode.

Due to improvements in the HVAC system, the energy retrofit actions will mostly focus on the building envelope and their energy results per climatic zone, and a lighting system replacement also has to be considered.

In the following section, the simulation inputs and implemented energy retrofit actions are described. It must be noted that, although Italy has 6 climatic zones (from A to F), there are only 2

Table 1
Envelope thermal characteristics.

	Thickness [m]	U-value (Model output) [W/m^{2}K]	
External walls	0.33	2.70	U_{ew}
Internal walls	0.12	1.79	U_{iw}
Roof	0.56	1.16	U_r
Ground-floor	0.81	0.68	U_g
Ceilings	0.25	1.76	U_c
Window	0.04e0.012-0.04	5.28	U_w

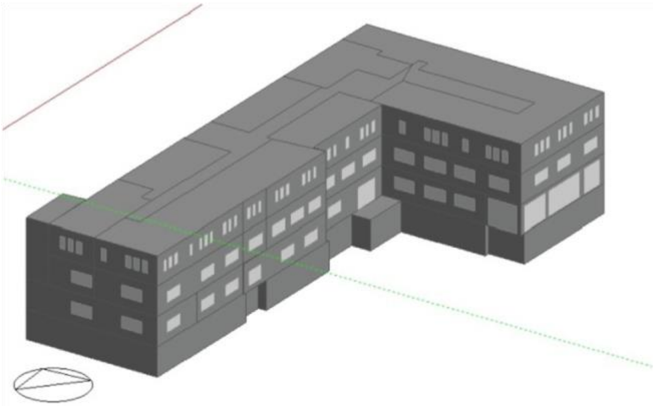

Fig. 1. Building 3-D model of the city hall.

Table 2 Building losses surfaces.

Orientation	losses surface [m^2]	wall [m^2]	window [m^2]	ratio [%]
South-East Wall	419.22	313.02	106.20	0.25
South-West	124.38	77.41	46.97	0.37
North-West	389.07	341.53	47.54	0.12
North-East	205.11	82.81	122.30	0.59
External floor (portico)	70.91		e	e
Ground floor	730.21		e	e
Roof	730.21		e	e

Table 3
Operating HVAC systems.

City	climatic zone	HDD	heating period	hours/day
Palermo	B	751	1st Dec - 31st Mar	8

Cagliari	C	990	15th Nov e 31st Mar	10
Rome	D	1415	1st Nov e 15th Apr	12
Milan	E	2404	15th Oct e 15th Apr	14

municipalities in zone A and 1074 in zone F (13% of the Italian municipalities, corresponding to small Italian mountain communities). Hence, climatic zones B, C, D and E are chosen to represent the typical building occurrence throughout the Italian peninsula.

3.1. Building dynamic simulation

The building model was developed using DesignBuilder software [53], which was built around the EnergyPlus dynamic thermal simulation engine [54]. The dynamic model was first calibrated by performance of the building. The simulated scenarios, their description and the thermo-physical properties of the interventions are described with the DU with respect to the base case are reported in Table 4.

The selected retrofit actions are mostly focused on energy performance improvements in the building envelope and, in particular, the insulation of the opaque and transparent envelope with the application of insulation panels, according to Ref. [55,56].

Regarding internal thermal insulation, we can affirm that by using proper safety features it is possible to use VIP, which reduces energy consumption, avoiding moisture issues, while respecting facades of listed buildings.

Some simple actions should be implemented to install the Vacuum Insulation Panels, such as:

a) in positions where VIP are unsuitable (i.e. window-to-wall attachments), other insulation materials (i.e. glass wool) should be used; b) VIP could be installed within wood slats and its gluing could be done by using polyurethane glue; c) the connections among parts should be accurate in order to guarantee an efficient air seal over time; d) the internal surface should be regular, flat (without sharp parts) and smooth; e) the VIP panels can’t be exposed to temperatures above 100 C; f) to avoid moisture in the wall and on the panels, some vapour barriers should be used; and g) macroporous dehumidifying plasters should be used.

Additionally, the substitution of existing windows with doubleglazed argon filled windows and an aluminium frame with thermal break is suggested. Furthermore, a more efficient artificial lighting system consisting of LED lights with linear lighting control is proposed. Finally, a combination of some actions was simulated.

4. Energy simulation results

using the available monthly consumption electric billing data. The

In this section, the results determined by the energy simulation

actual yearly mean energy consumption of the building is are shown and analysed. In Fig. 3, the primary speciﬁc energy 41,960 kWhe, while the simulation results

in a value of consumption (kWh/m^{2}year) for each scenario with respect to BC is

41,778 kWhe. Once the calibrated model in Cagliari was finished, reported.
the building was simulated in Palermo, Milan and Rome, and the

The simulation results show that the action TC can lead to a

results of the benchmarks are shown in Fig. 2. great reduction of the heating demand in all cases; however, it

As expected, the building requires an increased heating demand signiﬁcantly increases the cooling demand due to the increase in according to the climatic zone and to the operating hours of the the thermal inertia and then of the shift phase of the thermal wave
HVAC system. However, the highest cooling demand occurs in clithat causes higher cooling energy requirement. The WS (Window
matic zone B (Palermo). substitution þ Shading devices) and W (Window substitution)

Then, several combinations of the seven energy upgrades in the retroﬁt actions in zones B, C and E increase the heating demand but targeted building for each of the four considered climate zones contribute to a decrease in the cooling need. The TC þ RI seems to

were simulated, according to the Italian financing programme be the scenario that best contributes to the heating energy demand
“Conto Termico 2” and the Italian law concerning historic building reduction. Generally, in all climatic zones, the LED þ LC (Lighting
heritage preservation. Therefore, beyond the four previous benchsources substitution with LED þ linear Lighting Control) scenario
marks, 28 scenarios were simulated by implementing either a increases the heating energy savings, while the cooling demand unique intervention or by combining some of them to evaluate the shows a small increase. The yearly energy consumption for artiﬁcial contribution of each action to the improvement of the energy

lighting end-use decreases from 12,274.51 KWhe/year to 8862.32 KWhe/year in all scenarios.

Furthermore, to present the results in a clear manner, Table 5 displays the specific primary energy demand (sPE) and saving percentage (with respect to the BC) per climatic zone and scenario.

In Table 6, it is worth noting that a few of the proposed energy retrofit actions are suitable (cells filled with green), while it can be noted that the energy-ineffective measures per heating and cooling demands are in the grey cells. Moreover, by considering the heating demand, the WS action results are only efficient in zone D, where all actions are suitable with a top savings of 62.2% in the TC þ RI scenario.

The WS (Window substitution þ Shading devices) and W

(Window substitution) scenarios contribute to an increased heating demand in zones B and C due to the regulatory constraints of “Conto Termico 2.0”, financing window substitution and

shading devices or

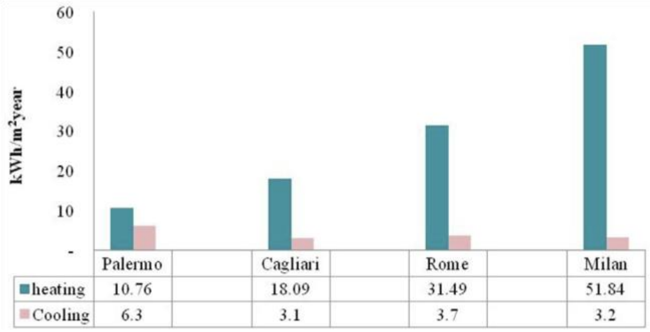

Fig. 2. Specific primary energy consumption of benchmarks (BC).

Table 4
List of the proposed retrofit actions.

Scenario	Description
BC	Base Case

TC	Thermal coat application (internal)
RI	Roof Insulation
WS	Window substitution þ Shading devices
W	Window substitution
TC þ RI	Thermal coat application þ Roof Insulation
TC þ RI þ WS	Thermal coat insulation þ Roof Insulation þ Window substitution þ Shading devices
LED þ LC	Lighting sources substitution with LED þ linear Lighting Control

Thermo-physical properties of the scenarios

	U-post [W/m^2K]	DU ¼ (U pre-U post) [W/m^2K]
TC	0.34	2.36
RI	0.32	0.84
W	3.00	2.28

window substitution only in east, south-east and west orientations. The lower solar radiation load in the winter season entails a small heating demand increase. Finally, it is possible to note that the cooling demand increases in the TC (Thermal coat application (internal)) and TC þ RI (Thermal coat application þ Roof Insulation) scenarios, while significant energy saving is achieved in the TC þ RI þ WS scenario. This fact is due to the free entrance of solar radiation that contributes to an increased heating load in a building with a very performant envelope (causing slow heating losses) and then an increased cooling demand. In addition, by also improving the transparent envelope, the TC þ RI þ WS scenario obtained the best energy performance. In Table 6, the overall specific primary energy demand and the related saving percentage are shown with the best (green cells) and worst (grey cells) energy results of each scenario highlighted.

In Table 7, Energy Priority Actions (EPA) are scored on a scale from 1 (most important) to 7 (least important) in the different scenarios of the retrofit actions that were simulated for the four climatic zones. The avoided emissions of CO2 in tonnes per year are also shown. According to the ENEA National Guidelines [57], the converting factor from kWhe to kWh of primary energy is 2.42, while the converting factor 0.46 kg/kWh is used to calculate the avoided CO_2. Looking at Table 7, it must be noted that the best scenarios in all climatic zones are the TC þ RI þ WS and TC þ RI scenarios.

5. Economic feasibility

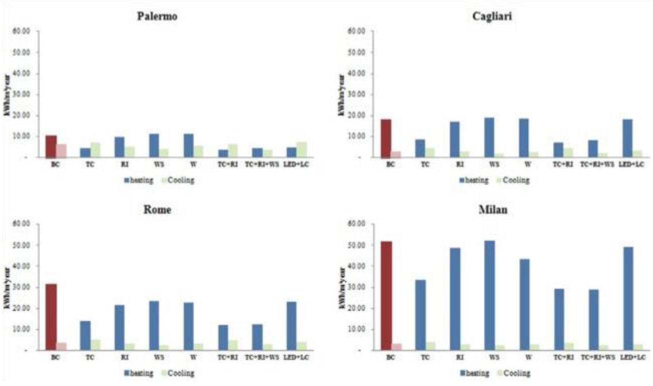

Fig. 3. Primary energy requirement of the building per each scenario.

A simplified economic analysis is conducted, taking into account the “Conto Termico 2” initiative and Eq. (1) listed above. The results displayed in Table 8 show the specific cost of each intervention and the related involved area. Furthermore, I_{max} and I_{TOT} by energy measure are shown in detail. The I_{max} value represents the maximum economic incentive per action (40% of the total cost), and, in some cases, it can be the sum of two or more interventions, such as the proposed TC þ RI þ WS action. In this case, Imax has a limit range that is between V 250,000 for the TC þ RI and V 75,000 for the WS retrofit action.

5.1. Economic indicators

According to Ref. [51], the analysis described in this section is based on the evaluation of the PayBack time (PBT), which is a function of the Net Present Value (NPV_n) indicator, defined as the sum of the present incoming and outgoing Cash Flows ($CF_{infþint}$) and the Present Value (PV) over a period, as reported in Eq. (2). Furthermore, the “Conto Termico 2” incentives were taken into account in the calculation.

$$NPV_n \text{ ¼} CF_{infþint} \text{ þ } PV \qquad (2)$$

Incoming and outgoing $CF_{infþint}$ is defined as reported in Eq. (3).

$$CF_{infþint} \text{ ¼ } DFC_n \frac{1þ I_{inf;n}}{1þ I_{int;n}} \qquad (3)$$

where DCF_n is the Discounted Cash Flow, and $I_{inf,n}$ and $I_{int,n}$ are the inflation and the interest rates, respectively. The DCF_n is a function of the Fuel cost (FC), the ratio between the primary Energy Saving (sPE) and the Lower Consumption Value (LCV), the sPE considers the difference between the primary energy consumption before and after the retrofit action application.

In Table 9, the PayBack time for each scenario in all climatic zones is collected. To have an overall framework for the effectiveness of the incentives, a PBT calculation with and without a government economic contribution was made. Indeed, as shown in Table 9, the absence of support mechanisms would make it impossible to apply the majority of the energy measures in climatic zones D and E; in addition, in the incentive measures in the climatic zones B and C, only TC and LED þ LC actions have a Payback Time less than 30 years (grey cells). It is interesting to note the application of the same measure in the same way among the different climatic zones.

Furthermore, by analysing the low energy and economic conveniences of several proposed retrofit actions, we finally suggest

Table 5

Heating and cooling specific Primary Energy demand (sPE) and saving (%) per each scenario.

Heating	Palermo (B)[a]		Cagliari (C)[a]		Rome (D)[a]		Milan (E)[a]	
	PE	Saving	PE	Saving	PE	Saving	PE	Saving
	[kWh/m^{2}y]	[%]	[kWh/m^{2}y]	[%]	[kWh/m^{2}y]	[%]	[kWh/m^{2}y]	[%]
BC	10.76		18.09		31.49		51.84	
TC	4.52	58.0%	8.64	52.3%	13.92	55.8%	33.40	35.6%
RI	9.76	9.2%	17.15	5.2%	21.60	31.4%	48.94	5.6%
WS	11.28	¡4.9%	19.16	¡5.9%	23.67	24.8%	52.13	0.6%
W	11.17	¡3.8%	18.43	¡1.9%	22.83	27.5%	43.28	16.5%
TC þ RI	3.59	66.6%	7.08	60.9%	11.91	62.2%	29.16	43.7%
TC þ RI þ WS	4.58	57.4%	8.27	54.3%	12.62	59.9%	28.90	44.3%
LED þ LC	4.78	55.5%	18.34	¡1.4%	23.07	26.8%	49.31	4.9%
COOLING	Palermo (B)[a]		Cagliari (C)[a]		Rome (D)[a]		Milan (E)[a]	
	PE	Saving	PE	Saving	PE	Saving	PE	Saving
	[kWh/m^{2}y]	[%]	[kWh/m^{2}y]	[%]	[kWh/m^{2}y]	[%]	[kWh/m^{2}y]	[%]
BC	6.3		3.1		3.7		3.2	
TC	7.1	¡14%	4.5	¡48%	5.1	¡37%	4.2	¡29%
RI	5.3	16%	2.8	8.6%	3.4	9.6%	2.8	14.2%
WS	4.0	36%	1.8	40.8%	2.5	32.5%	2.4	27.1%
W	5.4	14%	2.7	11.6%	3.4	9.7%	3.0	8.2%
TC þ RI	6.3 3.8	¡1%	4.3 2.0	¡40%	4.7 2.9	¡27%	3.5 2.4	¡9%
TC þ RI þ WS		40%		35.3%		21.9%		26.7%
LED þ LC	7.4	¡18%	3.2	¡6%	3.9	¡5%	2.9	10%

[a] Climatic zone.

Table 6

Overall specifi

ergy demand (sPE) and sa

	Palermo (B)*		Cagliari (C)*		Rome (D)*		Milan (E)*	
	sPE	Saving	sPE	Saving	sPE	Saving	sPE	Saving
	[kWh/m^{2}y]	[%]	[kWh/m^{2}y]	[%]	[kWh/m^{2}y]	[%]	[kWh/m^{2}y]	[%]
BC	17.04		21.15		35.21		55.07	
TC	11.66	32%	13.18	38%	19.04	46%	37.57	32%
RI	15.05	12%	19.94	6%	24.97	29%	51.71	6%
WS	15.31	10%	20.97	1%	26.18	26%	54.49	1%
W	16.60	3%	21.14	0%	26.19	26%	46.25	16%
TC þ RI	9.91	42%	11.37	46%	16.63	53%	32.69	41%
TC þ RI þ WS	8.33	51%	10.26	52%	15.52	56%	31.27	43%
LED þ LC	12.18	29%	21.58	¡2%	26.99	23%	52.22	5%

Table 7 y action (EPA) per scena 2.

Priority retrofit action								
	Palermo (B)*		Cagliari (C)*		Rome (D)*		Milan (E)*	
	EPA	Avoided tCO$_2$/y	EPA	Avoided tCO$_2$/y	EPA	Avoided tCO$_2$/y	EPA	Avoided tCO$_2$/y
TC	3	6.10	3	9.04	3	18.32	3	19.82
RI	5	2.26	4	1.37	4	11.60	5	3.81
WS	6	1.97	5	0.21	5	10.23	7	0.66
W	7	0.50	6	0.02	6	10.22	4	9.99
TC þ RI	2	8.08	2	11.08	2	21.05	2	25.35
TC þ RI þ WS	1	9.87	1	12.34	1	22.31	1	26.96
LED þ LC	4	5.51	-	-	7	9.31	6	3.22

adding a PV system to partially provide the needed energy demand of the building, especially because the considered zones are characterized by a significant amount of solar radiation availability. The suggested system is an on-grid PV system with a 50 kWp nominal capacity and is installed on an exposed area near the studied building. In this case, the electricity production was estimated in the 4 climatic zones using PVGIS software [58]. The simulations were carried out for one year with the following parameters:

polycrystalline modules, ground based with no shading, an azimuth angle of 0 and an optimized annual tilt angle of 30. The simulation results are shown in Fig. 4 for the four cities of the considered climatic zones.

The results show a potential solar yield in the different climatic zones, especially in Palermo. Therefore, the decision about a PV installation in addition to the described retrofit actions would represent an advantage to reduce the PayBack times.

The PV system energy production coupled with the energy savings of different retrofit actions are reported in Table 10 for each scenario.

In climate zone E, and, in particular, in cases of BC, RI, WS, W and LED þ LC, the PV system contributes to reducing the grid energy demand only. Specifically, if we consider the results obtained from PVGIS software in the green cells of Table 11, it can be noted that an energy surplus exists for each scenario, while, in the grey cells (all in climatic zone E), the specific energy consumption is not covered by the PV system.

Table 8
Overall costs of retrofit action and “Conto Termico 2” maximum incentives.

Scenario	Area	Specific cost[a]	Total costs	I_{max}	I_{TOT}
	m2	[V/m^2]	[V]	[V]	[V]
TC	885.68	60	53,140.8	250,000	21,256.32
RI	730.21	60	43,812.6	250,000	17,525.04
WS	323.01	450	145,354.5	75,000	58,141.80
W	323.01	350	113,053.5	75,000	45,221.40
TC þ RI	1615.89	120	193,906.8	250,000	77,562.72
TC þ RI þ WS	1938.9	570	1,105,173	325,000	325,000.00
LED þ LC	2169.3	35	75,925.5	70,000	30,370.20

[a] The specific cost [V/m^2] derives by regional mean costs.

Finally, by assuming an economic cost of the PV system (without government incentives) for the BC, RI, WS, W and LED þ LC retrofit actions, the Payback times were calculated (Table 11).

6. Conclusion

In this research, a “typical” historic public building that requires energy refurbishment was investigated to identify the most appropriate retrofit solutions, which can be applied in line with governmental financing incentives. Seven detailed energy strategies have been applied on a base case (BC) building in four different climatic zones in Italy.

According to previous research and scientific approach, a rigorous study has been conducted in this work, in order to identify potential energy saving of public historic buildings, and principally, to highlight limitations of current Italian energy policies about this topic. It is important to mention that the development of Italian Governmental database about historic public buildings with particular focus on their use, occupancy, layout, envelope, thermalenergy characteristics, and energy consumption ..., would increase accuracy and relevance of the findings.

By analysing the simulation results, some interesting conclusions can be highlighted with respect to the BC scenario. The WS and W actions contribute to an increasing heating consumption of the building in climatic zones B, C and E. The TC and TC þ RI scenarios show an increase in the cooling consumption in all climatic zones. However, in zone E only, the LED þ LC strategy contributes to a decrease in the cooling demand. This fact is also confirmed by previous studies conducted by ENEA on a building sample located in Italy.

Moreover, if the specific primary energy saving is considered, the scenario TC þ RI þ WS seems to be the best retrofit action in all climatic zones, while the worst scenarios are the W and WS actions in climatic zones B and E, respectively.

Furthermore, an economic analysis involving the governmental energy incentive measures was made, and the feasibility results show that the best energy actions (such as TC þ RI þ WS) have a PayBack time (PBT) larger than 30 years, making it difficult to implement the action.

Table 9
PayBack times of each scenario.

	TOTAL COST	Palermo		Cagliari		Rome		Milan	
	[V]	no incentives	CT2	no incentives	CT2	no incentives	CT2	no incentives	CT2
PayBack Times [years]									
TC	53,140.80	24	18	19	15	12	9	11	8
RI	43,812.60	>30	>30	>30	>30	15	10	>30	22
WS	145,354.50	>30	>30	>30	>30	>30	24	>30	>30
W	113,053.50	>30	>30	>30	>30	>30	21	>30	21
TC þ RI	193,906.80	>30	>30	>30	>30	25	19	23	17
TC þ RI þ WS	911,283.00	>30	>30	>30	>30	>30	>30	>30	>30
LED þ LC	43,386.00	24	17	>30	>30	20	14	>30	23

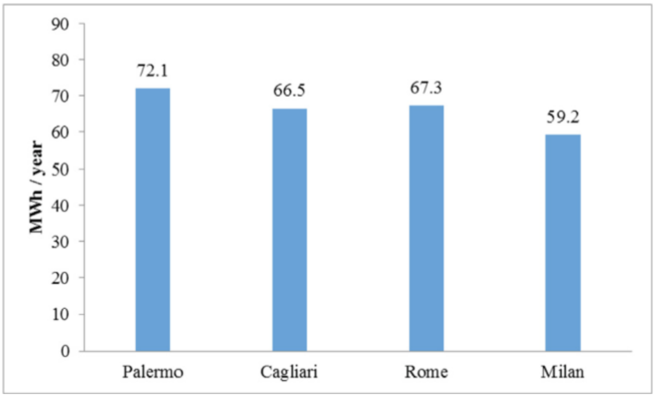

Fig. 4. PV system energy production (MWh/y).

Table 10
PV system energy specific production and energy surplus per each scenario.

	Palermo	Cagliari	Rome	Milan
	kWhe/m^2			
Specific PV production	29.29	27.03	27.35	24.06
BC	14.02	10.06	4.57	6.92
TC	16.35	13.46	11.36	0.41
RI	14.85	10.56	8.81	5.53
WS	14.74	10.14	8.31	6.68
W	14.21	10.07	8.30	3.28
TC þ RI	17.07	14.20	12.35	2.42
TC þ RI þ WS	17.72	14.66	12.81	3.01
LED þ LC	17.46	11.37	9.27	4.70

This fact indicates that not all energy retrofit actions are suitable and efficient around Italian climatic zones.

As a solution, the authors proposed installing a PV system coupled to some retrofit actions to reduce the PBT. Therefore, the worst retrofit actions can become suitable due to the significant PayBack time reduction and can lead to clean electrical energy production.

Finally, based on the performed analysis, the authors can affirm the following.

- Although the energy quality improvement of the building envelope could be considered a good action, the energy/economic balance shows ineffectiveness in all climatic zones due to large PayBack times.
- The best retrofit action is often combined with clean energy production; therefore, the Italian government should reconsider the strict standards concerning the PV applications to historic buildings.
- Government energy measures should be more focused on the specific national climatic zones, especially for measures acting on the building envelope.

Table 11
Payback Times of less attractive scenarios (climatic zone E).

Payback Times		
Milan	total cost [V]	years
BC þ PV	50,000.0	4
RI þ PV	93,812.6	7
WS þ PV	195,354.5	12
W þ PV	163,053.5	10
LED þ LC þ PV	93,386.0	7

This study would provide a starting point for further studies in this field. However, the first step of this path should be performed by the Italian Government, improving tools, databases and regulations to move towards energy self-sufficiency.

Nomenclature

HDD	Heating Degree Days []
S_{PE}	Primary Energy Saving [kWh]
LCV	Lower consumption Value [kWh]
$CF_{infþint}$	Cash Flow depending on inflation and interest rate [V]
I_{inf}	inflation rate
I_{int}	interest rate
NPV	Net Present Value
PV	Present Value [V]
CFs	Cash Flows [V]
DCF	Discounted Cash Flow [V]
Fc	Fuel cost [V]

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