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Energy retrofit of historic buildings in the Mediterranean area: the case of the Palaeontology Museum of Naples

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Abstract

This paper aims to identify some optimal system solutions for the energy refurbishment of a specific historic building, through energy simulations in dynamic conditions performed with a suitable software. The analysis is carried out by the evaluation of energy requirements of the building, in terms of both primary and electric energy. The hypotheses of intervention regard only the air conditioning system components and take into account the existing architectural constraints. The case study refers to the Palaeontology Museum of Naples (Southern Italy), whose rooms are currently in a historic building located in the ancient centre of the city.

Keywords: Historic buildings; Case study; Energy refurbishment; HVAC systems; Simulation software.

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1. Introduction

Nowadays, one of the main topics of discussion regards the energy consumption, as well as the related natural resources exploitation and pollutants emissions.

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In Europe, the greatest impact on the total energy requirements is given by the building sector, which is responsible of about 40% of the final energy consumption.

The EU-27 reports that in Europe there are 160 million buildings, but only 1-1.5% of them can be considered new buildings and about 14% date back to before 1919 [1]. Therefore, most of the buildings present poor energy performance and consequently high energy consumptions and relevant pollutant emissions. This implies that it is necessary to plain and carry out suitable energy retrofit measures of existing buildings, by applying various techniques.

It has been demonstrated [2,3,4] that it is possible to obtain satisfactory energy requirement reductions even by simply applying some innovative and non-invasive surface finishes.

Other researches [5] have instead addressed the problem of thermal bridges, which in the specific case were treated with insulating vacuum panels.

Some authors [6] have shown, specifically for office buildings, a suitable way to identify an effective thermal insulation for Mediterranean climates, both technically and economically.

A category of existing buildings characterized by high energy consumption is represented by historic buildings. For them, energy retrofit actions are more complicated because of architectural and artistic constrains that often oblige to preserve the integrity of the buildings. In Italy, there are many historic buildings, which are currently used for different functions, both in the public sector, such as offices and universities, and as private residences. With reference to this category of buildings, some authors [7] have evaluated the benefits produced by innovative integrated systems, which do not spoil the aesthetic appearance of the building, such as special tiles with high insulation properties. In the perspective of a sustainable future, it has been evaluated [8] the contribution obtained with the green retrofit applied on historic buildings.

Some research papers refer to real historic buildings. A historic building located in Benevento (Southern Italy), "Palazzo Bosco Lucarelli", administrative headquarter of the Engineering Faculty of the University of Sannio, was examined by some authors [9,10] using a multidisciplinary approach to optimise both the structural behaviour under seismic action and energy retrofit measures.

Another building in the city of Benevento, "ex-INPS" building, has been analysed to determine the correct approach to be adopted for the energy renovation of a historic building [11]. The innovative "cost-optimal" approach has been applied for energy retrofit of Palazzo Penne, a fifteenth century building located in Naples [12].

In Franco et al. [13], the best solutions to achieve high energy performance in view of a possible re-use of the building have been analysed for the "Albergo dei poveri", an abandoned building sited in Genoa (Northern Italy); also the possibility of including energy production systems from renewable sources has been considered.

This paper analyses the energy refurbishment of a historic building used as a museum, for which there is an increased degree of difficulty due to the nature of the elements contained in these structures: sometimes, the artworks exhibited in museums require specific temperature-humidity conditions for their preservation, and not always such conditions are compatible with the occupant thermal comfort.

In Bellia et al. [14] the best thermal conditions for the artworks conservation in the exhibition halls have been analysed. Through a multidisciplinary approach, in [15] suitable guidelines for simultaneously obtaining optimal conservation, energy efficiency and human comfort in museum buildings have been proposed.

Some research studies have also been carried out on real museums. With reference to the "Salone dei 500", a museum hall located in the "Palazzo Vecchio" in Florence, in Balocco and Grazzini [16] the authors verified the possibility to reach the ideal thermo-hygrometric conditions using mobile platforms with integrated radiant panels.

In Rota et al. [17], the authors in collaboration with the "Musei Senesi" Foundation have defined solutions to improve the museum energy efficiency with both active and passive systems.

In this paper, a real historic building, used as Palaeontology Museum of Naples (Southern Italy), is analysed to improve the indoor thermal-hygrometric conditions and reduce energy consumption of the air conditioning systems. To this aim, a software tool is used to carry out building energy performance simulations in dynamic conditions. Some possible different modifications of the air conditioning systems are analysed to minimize the energy requirement. The existing architectural constraints do not allow the energetic improvement of the building envelope.

Nomenclature

COP	Coefficient Of Performance
EER	Energy Efficiency Ratio
EU-27	European Union (27 countries)
HVAC	Heating, Ventilating and Air Conditioning

2. Methodology and case study

This section describes the characteristics of the case study, i.e. the Palaeontology Museum in Naples, mainly from architectural, geometric and material point of view, as well as the air conditioning systems currently installed in the building.

Moreover, the methodology used to analyse the building energy requirements is described, with reference to both the current state and some possible system modifications.

2.1. Methodology

The first stage has concerned the collection of information about the object of study; in particular, the building geometrical layout has been individuated (orientation, internal distribution and dimensions). For this purpose, an inspection has been carried out, to verify the information previously obtained; in that occasion, it was possible to count on the staff support. During the inspection, a complete information about the building materials and the HVAC system types present in the building has been acquired, together with a photographic documentation. The collected data have been useful for the realization of the model on which the energy simulations are performed, both in the current state configuration and with some proposals to improve the present system configuration.

The simulations are carried out in dynamic mode, and therefore the thermal flows involving the building and other useful parameters are evaluated according to an hourly and sub-hourly time unit.

2.2. Case study

As already mentioned, the case study refers to a historic building in which the Palaeontology Museum of Naples is located. The building is part of the "San Marcellino" complex, located in the ancient centre of Naples (declared World Heritage by UNESCO) and built between the 5th and 7th century.

The area used as a museum (about 637 m^2) is developed on one level (see Fig. 1). Most halls have exposure South/South-East; contrariwise, the halls towards North/North-West face on the large cloister of the said Complex and are protected by a deep porch (about 4.50 m).

The structure is characterised by masonry walls, specifically in Neapolitan yellow tuff, with high thickness, ranging between 1.0 m and 1.6 m, coated with plaster - unitary thermal transmittance of 0.648 W/(m^{2}K).

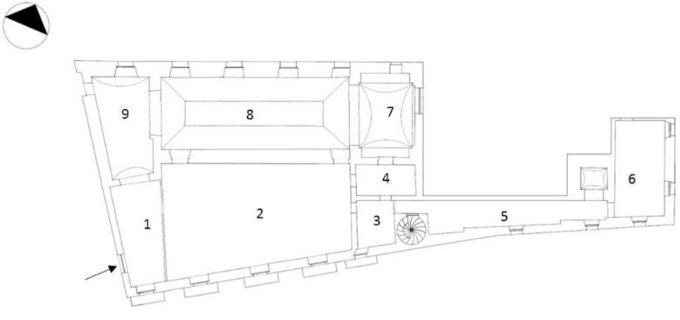


Fig. 1. Plan of Palaeontology Museum in Naples: 1) Atrium 2) Invertebrates hall 3) Sharks hall 4) O.G.C. hall 5) "Pietraroia" fish hall 6) Mammals hall 7) Mammuthus hall 8) Dinosaur hall 9) Ichthyosaurus hall.

The halls present different storey heights and diverse types of roof: in some halls, the roof is flat, while in others the roof is vaulted; the heights of the locals, measured at the intrados, are between 5.60 m and 7.50 m.

The windows are characterised, for the most part, by wooden frame and single glass, except those facing the cloister, that instead have an iron frame; in correspondence of the openings, sun screens consisting of white canvas panels supported by small wooden frames are installed.

With reference to lighting, two different types of lamps are installed: in some halls, there are fluorescent lamps installed in the ceiling, in others spotlights with metal halide lamps mounted on the wall. Moreover, for the conservation of small archaeological finds some glass theca are present, illuminated with fluorescent lamps.

Regarding the air conditioning systems, currently there is only a heating system, based on a no-condensing quite dated boiler and two different types of terminals. In the Atrium and in the Invertebrates hall, aeraulic terminals consisting of air diffusers installed in the countertop are present, while in Mammals hall, "Pietraroia" fish hall, Sharks hall and O.G.C hall there are hydronic terminals (fan-coil units). In the remaining halls (Mammuthus, Dinosaur and Ichthyosaurus halls), there is no device for heating or cooling.

2.3. Hypotheses of intervention

Based on the above description, it can be said that the main current problems are:

- absence of cooling system throughout all the museum locals;
- absence of both heating and cooling systems in three museum halls (Ichthyosaurus, Dinosaur and Mammuthus halls).

Given the historical importance of the building and the subsequent architectural constraints, improvements of the building envelope are avoided, while possible interventions refer exclusively to the air-conditioning system components. A brief description of these hypotheses of intervention follows, including some intermediate stages (for each configuration, related energy simulations are performed).

1) **No-condensing boiler (present configuration)**: it is that described in the previous section;
2) **Condensing boiler**: the first possible step consists solely in the replacement of the current boiler with a condensing boiler;
3) **Heat pump**: with this hypothesis, the boiler is replaced by an electrical air-to-water heat pump (only for heating);
4) **Condensing boiler + chiller**: in addition to the installation of a condensing boiler, a chiller is added to also ensure the cooling only in the halls currently equipped with system terminals;
5) **Reversible (or invertible) heat pump**: only in the halls currently equipped with system terminals, both heating and cooling are guaranteed by an electrical reversible air-to-water heat pump;
6) **Condensing boiler + chiller + packaged air conditioner units:** in addition to the equipment described in the case 4, three packaged air conditioner units are installed in halls currently without any air conditioning system (Ichthyosaurus, Dinosaur and Mammuthus halls);
7) **Reversible heat pump + packaged air conditioning units:** in addition to the equipment described in the case 5, three packaged air conditioning units are installed in halls currently without any air conditioning system.

There are two reasons that lead to propose packaged air conditioning units for three halls:

- the three halls to be air conditioned are characterised by vaulted ceiling and tiled floor subject to constraints of the Superintendent, therefore the installation of air channels or water pipes for serving aeraulic/hydronic terminals must be avoided;
- the chosen air conditioners do not have outdoor units, and therefore they do not affect the building facade.

2.4. Modelling and energy simulation

Energy simulations are performed by means of the software DesignBuilder [18], which is a graphical interface of the calculation engine EnergyPlus [19].

The geometry of the building is modelled (Fig. 2) and the characteristics of the building envelope components are assigned. The perimeter walls have a unitary thermal transmittance of 0.648 W/(m^{2}K). The other main assigned parameters are reported in the Table 1.

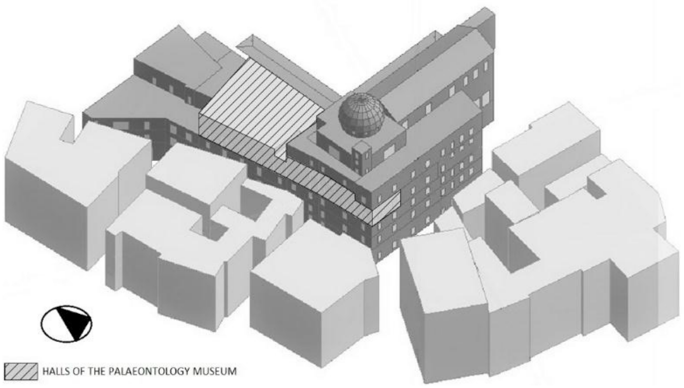


Fig. 2. Tri-dimensional model of the museum halls and the surrounding buildings.

Table 1. Main assigned parameters.

Parameter	Value	Unit of measure
Occupation level	0.15	person/m^2
Indoor air set-point temperature in winter	20	°C
Indoor air set-point temperature in summer	26	°C
Illuminance on the work plane (average value)	200	lux
Specific thermal load related to interior equipment	10	W/m^2

The museum opening hours are as follows:

- Monday and Thursday: 9:00/13:30 – 14:30/17:00;
- Tuesday, Wednesday and Friday: 9:00/13:30.

Period of operation of the HVAC system:

- heating from November 15 to March 31;
- cooling from 1 June to 30 September.

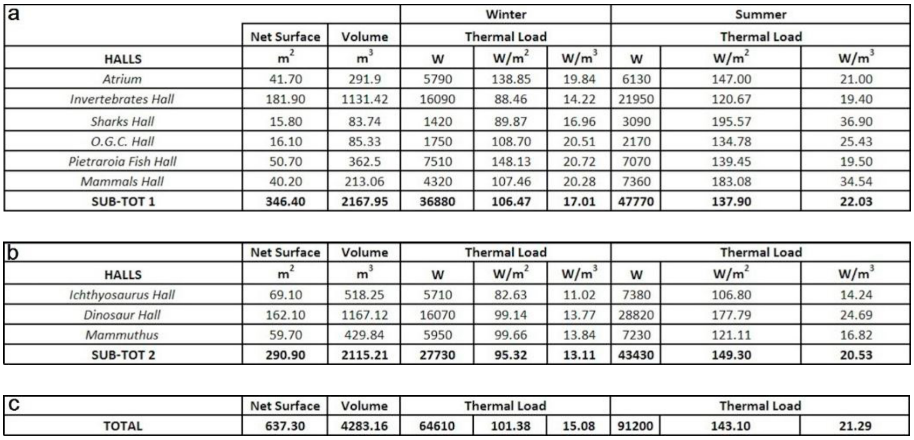
The efficiency values of the HVAC system components are reported in Table 2.

Table 2. Efficiency values of HVAC systems.

	No-condensing boiler	Condensing boiler	Heat pump	Chiller	Packaged air conditioning units
Global system efficiency	0.65	0.85	2.85	2.85	3.00
Component efficiency	0.90	1.05	-	-	-
COP	-	-	3.90	-	3.10
EER	-	-	3.90	3.90	3.10

3. Results

The first results concern the values of winter and summer thermal loads (Fig. 3), assessed for both the halls currently equipped with the heating system (Fig. 3a) and the three rooms currently without any system (Fig. 3b). Also, the values for the entire building are shown (Fig. 3c).



a

			Winter			Summer		
	Net Surface	Volume	Thermal Load			Thermal Load		
HALLS	m^2	m^3	W	W/m^2	W/m^3	W	W/m^2	W/m^3
Atrium	41.70	291.9	5790	138.85	19.84	6130	147.00	21.00
Invertebrates Hall	181.90	1131.42	16090	88.46	14.22	21950	120.67	19.40
Sharks Hall	15.80	83.74	1420	89.87	16.96	3090	195.57	36.90
O.G.C. Hall	16.10	85.33	1750	108.70	20.51	2170	134.78	25.43
Pietraroia Fish Hall	50.70	362.5	7510	148.13	20.72	7070	139.45	19.50
Mammals Hall	40.20	213.06	4320	107.46	20.28	7360	183.08	34.54
SUB-TOT 1	**346.40**	**2167.95**	**36880**	**106.47**	**17.01**	**47770**	**137.90**	**22.03**

b

	Net Surface	Volume	Thermal Load			Thermal Load		
HALLS	m^2	m^3	W	W/m^2	W/m^3	W	W/m^2	W/m^3
Ichthyosaurus Hall	69.10	518.25	5710	82.63	11.02	7380	106.80	14.24
Dinosaur Hall	162.10	1167.12	16070	99.14	13.77	28820	177.79	24.69
Mammuthus	59.70	429.84	5950	99.66	13.84	7230	121.11	16.82
SUB-TOT 2	**290.90**	**2115.21**	**27730**	**95.32**	**13.11**	**43430**	**149.30**	**20.53**

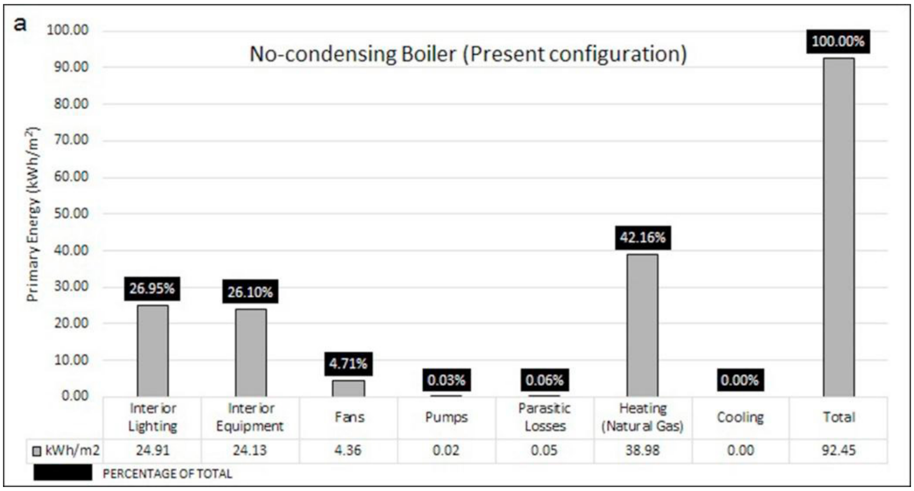
c

	Net Surface	Volume	Thermal Load			Thermal Load		
TOTAL	**637.30**	**4283.16**	**64610**	**101.38**	**15.08**	**91200**	**143.10**	**21.29**

Fig. 3. Winter and summer thermal loads of the museum halls.

A quite low summer thermal loads are obtained, mainly due to the high thermal inertia of the perimeter walls. Smaller values are related to the three halls with North/North-West exposure (Fig. 3b), which are also characterised by null or very low internal heat gains.

Fig. 4 shows the yearly primary energy requirements for all the proposed HVAC system configurations listed in the section 2.3.




b
Condensing Boiler
Primary Energy (kWh/m²)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
29.21%
28.29%
5.11%
0.03%
0.06%
37.30%
0.00%
100.00%
Interior Lighting
Interior Equipment
Fans
Pumps
Parasitic Losses
Heating (Natural Gas)
Cooling
Total
kWh/m2
24.91
24.13
4.36
0.02
0.05
31.81
0.00
85.29
PERCENTAGE OF TOTAL
c
Heat Pump
Primary Energy (kWh/m²)
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
33,47%
32,42%
5,85%
0,03%
0,07%
21,16%
0,00%
100,00%
Interior Lighting
Interior Equipment
Fans
Pumps
Parasitic Losses
Heating (Heat Pump)
Cooling
Total
kWh/m2
24.91
24.13
4.36
0.02
0.05
20.96
0.00
74.44
PERCENTAGE OF TOTAL
d
Condensing Boiler + Chiller
Primary Energy (kWh/m²)
120.00
100.00
80.00
60.00
40.00
20.00
0.00
21.39%
20.72%
6.76%
0.20%
0.05%
27.31%
23.57%
100.00%
Interior Lighting
Interior Equipment
Fans
Pumps
Parasitic Losses
Heating (Natural Gas)
Cooling (Chiller)
Total
kWh/m2
24.91
24.13
7.88
0.24
0.05
31.81
27.46
116.48
PERCENTAGE OF TOTAL

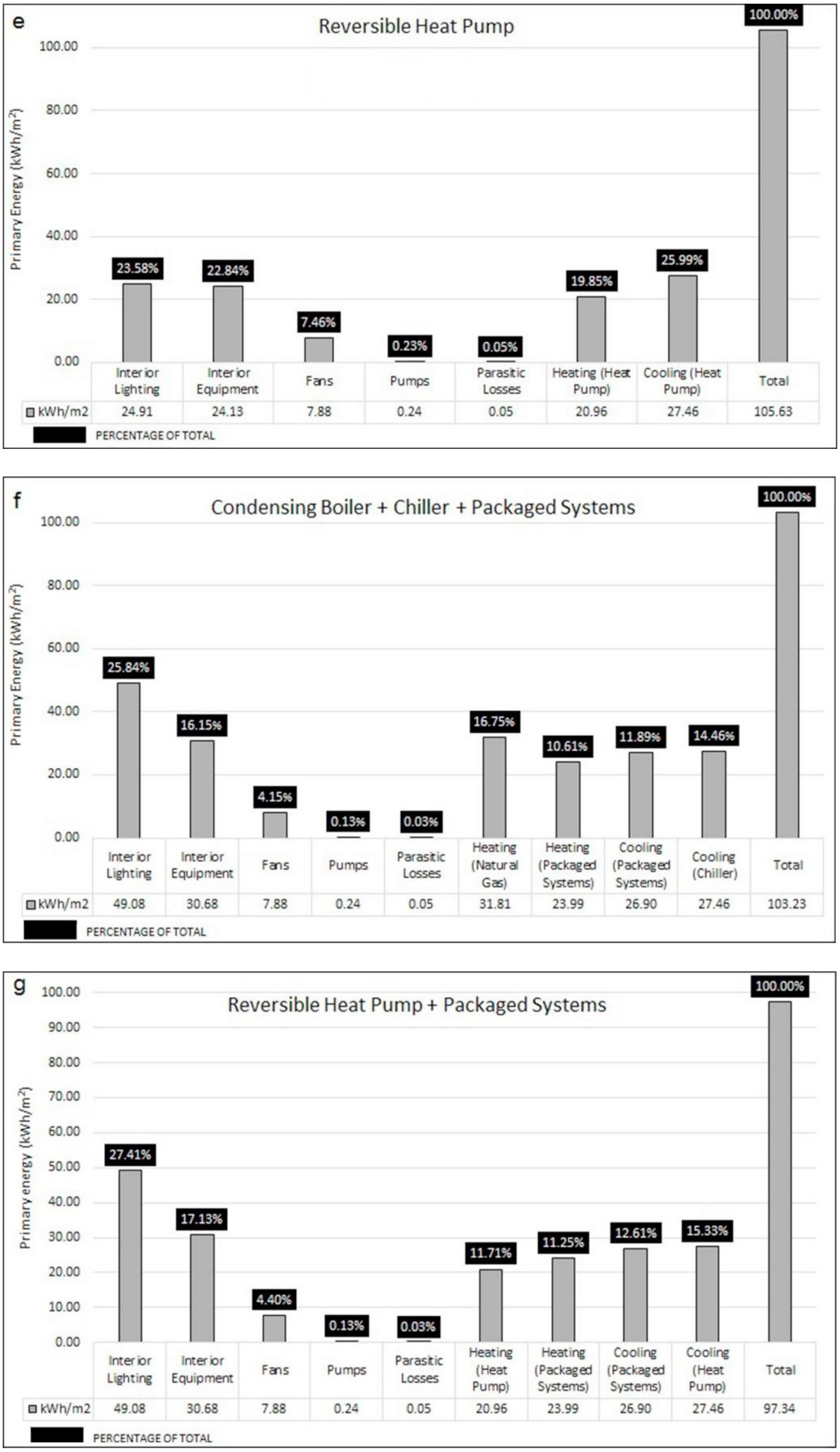


Fig. 4. Yearly primary energy requirements (kWh/m^2) for all the considered HVAC system configurations.

Comparing the first histograms (Figs. 4a, 4b, 4c), it can be observed that the simple replacement of the old heat generator with new and more efficient technologies (condensing boiler or heat pump) leads to considerable primary energy saving for heating (18%, 46% - Fig. 5). The incidence that the heating has on total energy demand is drastically reduced (from about 42% to 21% - Figs. 4a, 4b, 4c).

Even with the addition of cooling to the configuration with condensing boiler (Fig. 4d), heating system still keeps the greatest primary energy demand (27.3%); however, in the case of reversible (invertible) heat pump (Fig. 4e), the higher incidence is related to cooling (26%). Figs. 4f and 4g show the results in the case of the addition of the packaged systems (packaged air conditioning units) in the three halls currently without any HVAC system (Ichthyosaurus, Dinosaur and Mammuthus halls).

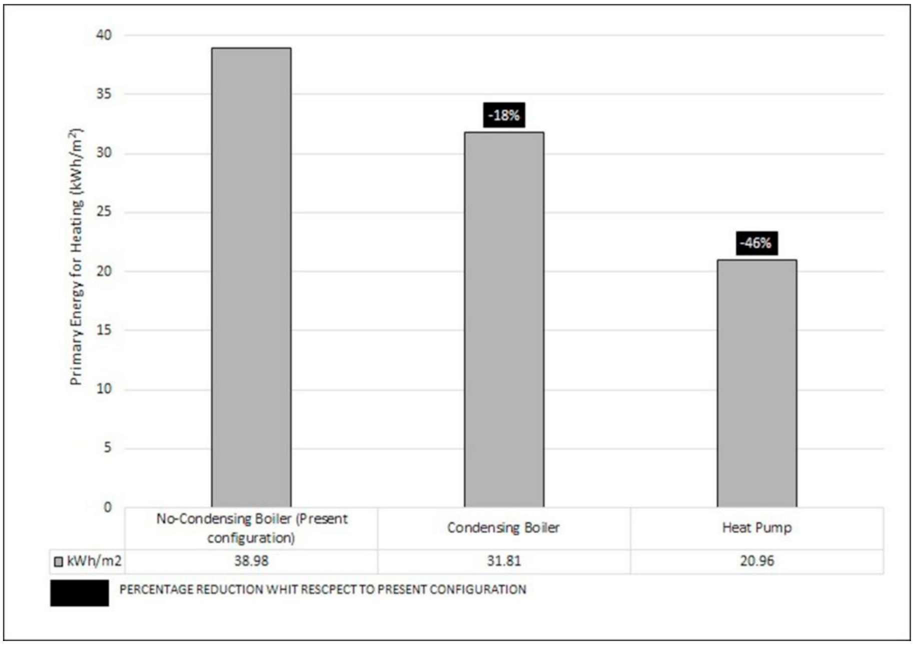
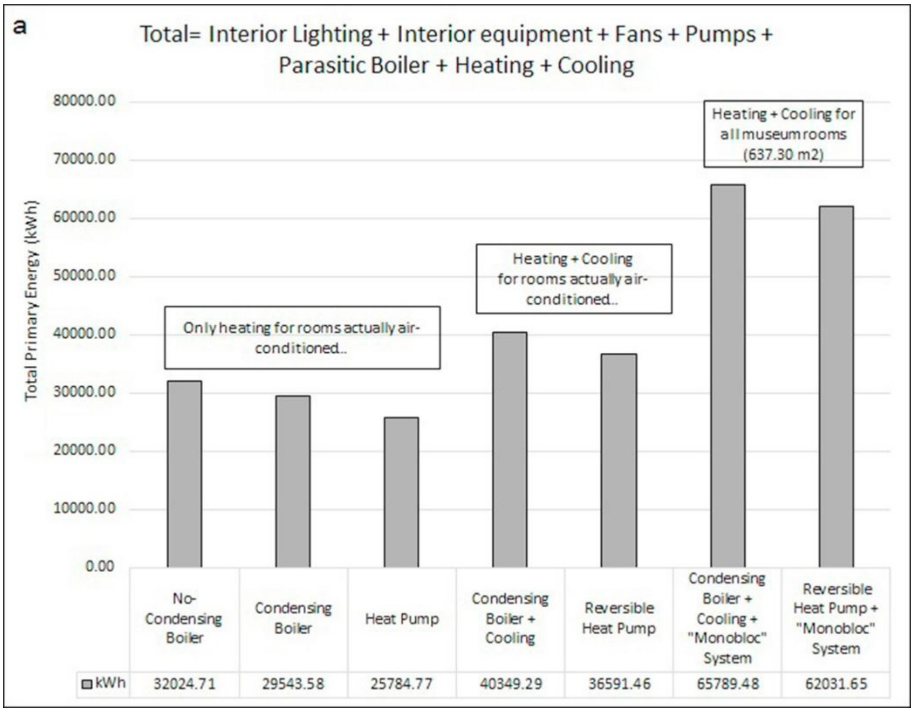


Fig. 5. Yearly primary energy requirements for heating (kWh/m^2) for the halls currently equipped with heating devices.

Finally, the results are reported in terms of total primary energy (Fig. 6) and total electric energy (Fig. 7) for each configuration.



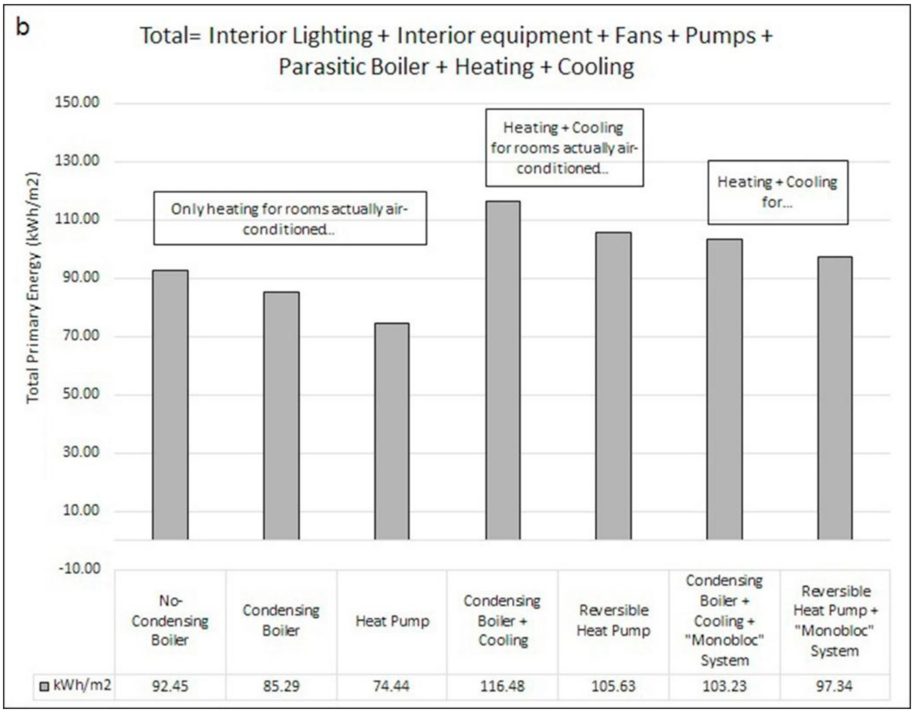


Fig. 6. Yearly total primary request for the different system solutions, expressed in a) kWh b) kWh/m^2.

The best result in terms of primary energy is obtained with the use of the heat pump (Fig. 6b), which is the most efficient and sustainable technology among those proposed. In particular, when installing the reversible heat pump and the packaged systems, a total primary energy request of about 97 kWh/m^2 is obtained.

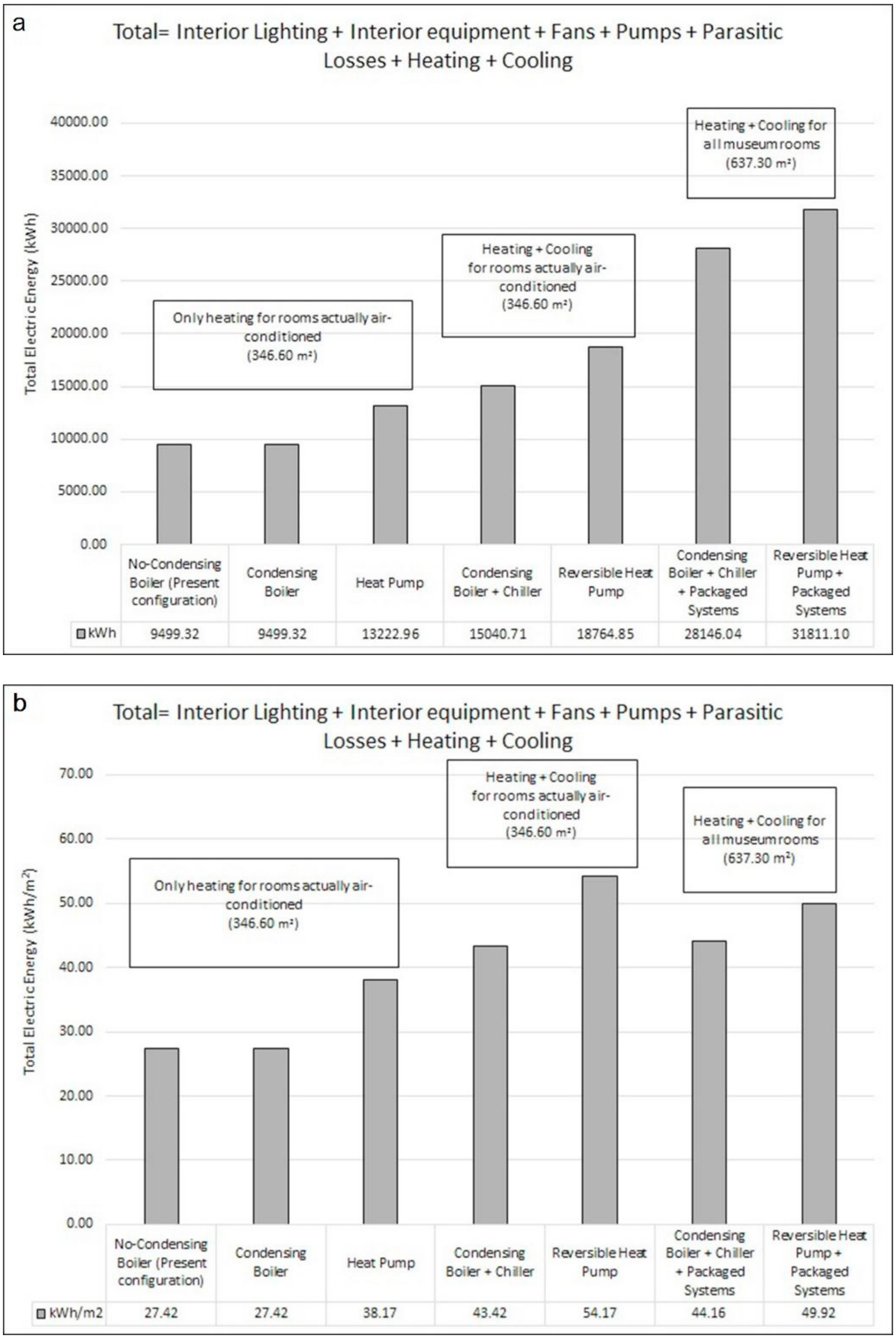


Fig. 7. Yearly total electric energy request for the different system solutions, expressed in a) kWh b) kWh/m^2.

This value is actually low for a historic building, but in this case it is justified considering the reduced museum opening hours and system operation periods.

Contrariwise, the best result in terms of only electric energy (Fig. 7) is obtainable with the configuration that includes condensing boiler, chiller and packaged systems (about 44 kWh/m^2), if both heating and cooling for all the museums halls are required.

4. Conclusions

This paper aims to identify some optimal system solutions for the energy refurbishment of a specific historic building, through energy simulations in dynamic conditions performed with a suitable software. The analysis is carried out by the evaluation of energy requirements, in terms of both primary and electric energy. The existing architectural constraints are also considered. The case study refers to the Palaeontology Museum of Naples (Southern Italy), whose rooms are currently in a historic building located in the ancient centre of the city.

Some possible HVAC system configurations are analysed, besides the current configuration which allows only heating in some halls (not in all the rooms).

Due mainly to the high thermal inertia of the walls, the calculated summer thermal loads are quite low, although the climate is quite warm, the building is very old and no energy retrofit measure on the building envelope is considered.

With reference to only heating system, the partial results show that the replacement of the existing old no-condensing boiler with a new condensing boiler would lead to a saving of 18% in terms of primary energy, rising 45% if an electric new air-to-water heat pump is considered instead of the boiler.

The best result in terms of total primary energy is obtained with the use of the heat pump, which is the most efficient and sustainable technology among those proposed as heat/cool generator. In particular, if both heating and cooling for all the museums halls are required, a primary energy request of about 97 kWh/m^2 is obtained when considering a reversible heat pump and three packaged systems for three particular museum halls (currently without any heating/cooling device).

It is also interesting to note that also the summer air conditioning, currently absent, can be allowed with an increase of only 5% in primary energy requirement compared to the current configuration (about 97 kWh/m^2 versus 92 kWh/m^2). The primary energy obtained value is actually low for a historic building, but in this case it is justified considering the reduced museum opening hours and system operation periods. Moreover, the primary energy for cooling is like that for heating.

Contrariwise, the best result in terms of only electric energy is obtainable with the configuration that includes condensing boiler, chiller and packaged systems (about 44 kWh/m^2), if both heating and cooling for all the museums halls are required.

References

[1] Popescu D, Bienert S, Schûtzenhofer C, Boazu R. Impact of energy efficiency measures on the economic value of buildings. Appl Energ 2012;89:454–63.

[2] Marino C, Minichiello F, Bahnfleth W. The influence of surface finishes on the energy demand of HVAC systems for existing buildings. Energ Buildings 2015;95:70-9.

[3] Marino C, Minichiello F. Existing buildings and HVAC systems: incidence of innovative surface finishes on the energy requirements. Energy Procedia 2015;82:499-505.

[4] Marino C. The optimal choice of the outside innovative surface finishes for buildings from a thermal and energetic point of view. Energy Procedia 2016;101:980-7.

[5] Isaia F, Fantucci S, Capozzoli A, Perino M. Vacuum Insulation Panels: thermal bridging effects and energy performance in real building applications. Energy Procedia 2015;83:269-78.

[6] de' Rossi F, Marigliano M, Marino C, Minichiello F. A Technical and Economic Analysis on Optimal Thermal Insulation Thickness for Existing Office Building in Mediterranean Climates. Int J Heat Technol 2016;34 Special Issue 2:S561-S568.

[7] Pisello AL, Petrozzi A, Castaldo VL, Cotana F. On an innovative integrated technique for energy refurbishment of historical buildings: Thermal-energy, economic and environmental analysis of a case study. Appl Energ 2016;162:1313-22.

[8] Filippi M. Remarks on the green retrofitting of historic buildings in Italy. Energ Buildings 2015;95:15-22.

[9] Ascione F, de' Rossi F, Vanoli GP. Energy retrofit of historical buildings: theoretical and experimental investigations for the modelling of reliable performance scenarios. Energ Buildings 2011;43:1925-36.

[10] Ascione F, Ceroni F, De Masi RF, de' Rossi F, Pecce MR. Historical buildings: Multidisciplinary approach to structural/energy diagnosis and performance assessment. Appl Energ 2015;185:1517-28.

[11] Ascione F, Bianco N, De Masi RF, de' Rossi F, Vanoli GP. Energy retrofit of an educational building in the ancient center of Benevento. Feasibility study of energy savings and respect of the historical value. Energ Buildings 2015;95:172-83.

[12] Ascione F, Cheche N, De Masi RF, Minichiello F, Vanoli GP. Design the refurbishment of historic buildings with the cost-optimal methodology: The case study of a XV century Italian building. Energ Buildings 2015;99:162-76.

[13] Franco G, Magrini A, Cartesegna M, Guerrini M. Towards a systematic approach for energy refurbishment of historical buildings. The case study of Albergo dei Poveri in Genoa, Italy. Energ Buildings 2015;95:153-9.

[14] Bellia L, Capozzoli A, Mazzei P, Minichiello F. A comparison of HVAC systems for artwork conservation. Int. J. Refrig 2007;30(8):1439-51.

[15] Lucchi E. Multidisciplinary risk-based analysis for supporting the decision making process on conservation, energy efficiency, and human comfort in museum buildings. J Cult Herit 2016;22:1079-89.

[16] Balocco C, Grazzini G. Plant refurbishment in historical buildings turned into museum. Energ Buildings 2007; 39:693-701.

[17] Rota M, Corgnati SP, Di Corato L. The museum in historical buildings: energy and systems. The project of the Fondazione Musei Senesi. Energ Buildings 2015;95:138-43.

[18] U.S. Department of Energy. DesignBuilder version 3.2.0.67.

[19] EnergyPlus. Documentation Getting Started with EnergyPlus Basic Concepts Manual - Essential Information You Need about Running EnergyPlus. https://energyplus.net/sites/default/files/pdfs_v8.3.0/GettingStarted.pdf