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ScienceDirect

Energy Procedia 159 (2019) 192–200

Energy Procedia

www.elsevier.com/locate/procedia

Applied Energy Symposium and Forum, Renewable Energy Integration with Mini/Microgrids, REM 2018, 29–30 September 2018, Rhodes, Greece

Villas on Islands: cost-effective energy refurbishment in Mediterranean coastline houses

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Abstract

This paper aims to underline the variability of constructions in Mediterranean regions, where different climates, architectural techniques and kinds of building uses determine different optimal energy refurbishments of residential buildings placed on the coastline. More in detail, by considering two different construction technologies (i.e., a lightweight house in reinforced concrete and a massive tuff-made villa), two different climates (Greek coast, climate of Athens and Italian coast, climate of Naples), two cost-optimal energy retrofits are presented. The optimized energy retrofit, performed by coupling transient energy simulations and genetic algorithm for generating improved models, have taken into account all levers of energy efficiency, and thus optimization of building envelope (thermal insulation, reflectance, windows and solar screens), active energy systems (daylight control, HVAC systems for the regulation of indoor conditions) and renewable energy sources at the building scale (namely, solar photovoltaic).

Keywords: Energy audit; Energy simulation; Modelling calibration; Energy saving; Occupant behaviour; University building.

1. Introduction and novelty of this study

It is well known that the main responsible of energy use, energy waste, polluting emission and thus anthropogenic negative impact of the world climate is the building construction sector. Moreover, it should be noted that the more

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1876-6102
10.1016/j.egypro.2018.12.050

and more pressing requests of comfort, according to all point of views (lighting comfort, thermal comfort, hygrometric comfort) are determining a constant increase of active energy systems installed in our houses so that, only as example, the most part of residential buildings, also at Mediterranean level, is now equipped with systems and equipment for cooling. Only some years ago, this energy use was absent so that, even if the available technologies improve their energy efficiency, this increment of efficacy is partly or completely nullified by the increase of users' expectation in matter of comfort. On the other hand, when cost reasons or energy availability are not so capillary diffused, the so-called phenomenon of energy poverty occurs, with all negative impacts described, for examples, by milestone papers of Santamouris [1] and Santamouris *et al*. [2, 3] and recently by Scarpellini *et al*. [4]. About it, it should be noted that there is also a special office of the European Institution aimed at contrasting the energy poverty [5]. This poverty, in presence of increasing heat islands effects (that exasperate the need of cooling) produces serious diseases, sickness, mortality.

The strong use of active energy systems is also more accentuated when dwellings are used/rented also for vacations and holidays, being the tourists probably more interested to comfort compared to the economic savings (that are typically an aim of building owners). On the other hand, Mediterranean areas offer beautiful places to preserve, and preservation means also a lower impact of pollution due to power plants, preservation of landscape by avoiding too exaggerated wind farms, preservation from all concerns the intensive use of energy that means, in general, depletion of the climate and of the natural integrity.

This paper concerns the energy retrofit of sea dwellings, by taking into account all levers of energy efficiency, and thus thermal envelope, active energy systems, renewable energy sources [6]. Generally, many papers have been published about the energy refurbishment in the building sector. Asadi et *al.* [7] proposed a new framework, which combines the potentialities of a genetic algorithm and an artificial neural network, with the aim to minimize the required investment cost, the energy demand for space conditioning and the discomfort hours, by proposing interventions on the energy systems and on the envelope. Karmellos et *al.* [8] provided a software that implements an optimization methodology based on a multi-objective mixed-integer non-linear problem, in order to minimize the initial investment cost and the primary energy consumption for both new and existing buildings. Moreover, Wu *et al.* [9] proposed a novel methodology concerning envelope, energy systems and renewable energy sources, in order to reduce the greenhouse gases' emissions and the costs during the lifecycle of an already existing building. However, the proposed paper considers different architectural and technological peculiarities, and this is quite new, as well as different available budgets for refurbishing [10]. The considered houses, of course, are merely examples of what the Mediterranean context can offer and also the building modelling want to be more generic is possible. In detail, a massive building typical of ancient villas is considered, as well as the relatively new summer houses built all around Europe. Finally, the simplistic diversification of Modern Greek house and Italian ancient villa will be given only for examples purposes, by well-knowing that ancient buildings can be found in every country of Europe as well as modern buildings built in reinforced concrete and with lightweight structures.

In conclusion, the entire study has to be intended, besides the interesting results, also as the proposition of a method for facing the problem, and thus an accurate approach to the energy refurbishment, by taking into account the available energy conservation measures (also for preserving the architectural integrity of particular houses), the climate, the cost of energy, the simplicity in using some technologies, the availability of renewable energy sources. Typically, in the Mediterranean coastline, the availability of sun is a constant, so that the profitability of solar photovoltaics is 'constant' too. In the next lines, the case study buildings will be described, as well as the climates and the other parameters used for energy optimization.

2. Description of the cases studies, of the climates and boundary conditions for the numerical optimizations

Both buildings, depicted in figure 1, have an overall useful area of around 300 m^2, constituted by three usable floors above the ground, each one with a surface strictly higher than 100 m^2. All rooms of the buildings (with the exceptions of couples of the white lightweight structure, that are only "aesthetical") are air-conditioned, by means of simple direct expansion systems for heating and cooling. The simulated ancient villa has a masonry structure, with tuff-walls plastered on both sides. The lightweight modern house, built with a structural frame of pillars and beams in reinforced concrete, has non-insulated external walls with a composite structure, with vertical cladding made in hollow blocks, without thermal insulation, plastered on both the sides. As anticipated, for both the buildings, windows are made with wood frames and single glasses, with an overall thermal transmittance (average values of glass and frame, namely $U_{windows}$) of around 5.9 W/m^{2}K, with a SHGC equal to 0.86. Analogously, for both buildings we have supposed old-technology direct expansion systems for heating and cooling, with coefficient of performance and energy efficiency ratios, at rated conditions, equal to 2.2 and 2.0 Wh_{TH}/Wh_{EL}, respectively. Other information about building geometry, composition of thermal envelope, heating and cooling systems and other boundary conditions are reported in Table 1 and Table 2, for the modern house and the ancient villa, respectively.

Figure. 1. a) Modern house in Greece and b) Italian Villa

Table 1. Geometry and modeling information of the modern house (Climate of Athens, Greece)

Area (m²)	338.4	Volume (m³)	1153	Net height of floors: 3.0 m		Climate		Athens (IWEC file)	
U_{wall} (W/m²K)	0.95	U_{slab} (W/m²K)	1.27		Total	North	East	South	West
U_{window} (W/m²K)	5.9	U_{roof} (W/m²K)	1.27	Gross Wall Area [m2]	498.5	84.7	164.5	84.7	164.5
Heating System Direct Expansion		COP 2.2		Window Opening Area [m2]	112.4	15.7	37.6	19.1	39.9
Cooling System Direct Expansion		EER 2.0		Gross Window-Wall Ratio [%]	22.5	18.5	22.9	22.5	24.3
Heating Degrees Days (Baseline 18 °C)			1112 Kd	Cooling Degrees Days (Baseline 18 °C)					1076 Kd
Lighting systems: fluorescent lamps (W/m²)			5	Electricity Source Conversion Factor					1.95
Electricity Price (€/kWh)			0.194	Electricity Selling Price (€/kWh)					0.065

Table 2. Geometry and modeling information of the ancient villa (Climate of Naples, Italy)

Area (m²)	300.6	Volume (m³)	1052	Net height of floors: 3.5 m		Climate		Naples (IWEC file)	
U_{wall} (W/m²K)	1.87	U_{slab} (W/m²K)	0.81		Total	North	East	South	West
U_{window} (W/m²K)	5.9	U_{roof} (W/m²K)	0.86	Gross Wall Area [m2]	449.0	72.9	151.6	72.9	151.6
Heating System Direct Expansion		COP 2.2		Window Opening Area [m2]	44.9	7.3	44.9	7.3	15.2
Cooling System Direct Expansion		EER 2.0		Gross Window-Wall Ratio [%]	10.0	10.0	10.0	10.0	10.0
Heating Degrees Days (Baseline 18 °C)			1364 Kd	Cooling Degrees Days (Baseline 18 °C)					756 Kd
Lighting systems: fluorescent lamps (W/m²)			5	Electricity Source Conversion Factor					1.95
Electricity Price (€/kWh)			0.214	Electricity Selling Price (€/kWh)					0.071

3. Simulations of the base scenarios: present energy performance

In order to provide both real or reliable representations of the buildings (before the refurbishments) and, secondly, in order to take into account the complexity of heat transfer in buildings mainly during the cooling seasons, when the dynamic and transient effects of thermal mass, thermal capacity, accumulation of thermal energy into the building structures cannot be neglected, a dynamic approach (BPS – Building Performance Simulation) was used for simulations, by means of EnergyPlus [11]. Only for the geometrical definition of the two buildings, the well-known and authoritative graphical interface DesignBuilder [12] was used. The main boundary conditions of simulations are in the following described: Conduction Transfer Functions as heat balance algorithm, dynamic heat balance by means of six timestep per hour, variable natural convection based on temperature differences for the surface convection inside, correlation from measurements for rough surfaces for the convection outside, 20 maximum iterations for the HVAC system. The climatic data are those of the authoritative ASHRAE IWEC [13].

In conclusion, in Table 3 are shown the simulation results in terms of building energy demand for heating, cooling lighting and other electric uses for both the case studies.

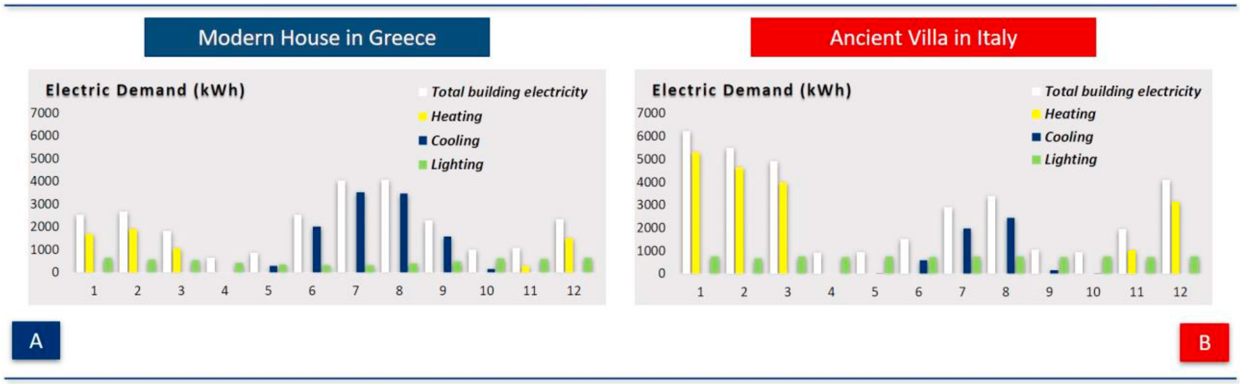

Figure. 2. Energy results of the reference scenarios: a) house in Greece and b) Italian Villa

Table 3. Overall scheme about energy consumption for both the baseline buildings

Modern House (Greece)	Heat (kWh_{el})	Cool (kWh_{el})	Light (kWh_{el})	Total building electricity (kWh_{el})	Ancient Villa (Italy)	Heat (kWh_{el})	Cool (kWh_{el})	Light (kWh_{el})	Total building electricity (kWh_{el})
January	1676	0	647	2541	January	5295	0	746	6235
February	1909	0	563	2669	February	4655	0	673	5504
March	1071	0	536	1826	March	3990	0	746	4929
April	0	0	431	642	April	0	0	722	909
May	0	288	352	859	May	0	2	746	942
June	0	2024	307	2542	June	0	596	722	1505
July	0	3511	324	4053	July	0	1970	746	2909
August	0	3458	396	4072	August	0	2454	746	3394
September	0	1591	491	2294	September	0	154	722	1063
October	0	156	617	991	October	0	6	746	946
November	282	0	598	1092	November	1037	0	722	1946
December	1490	0	644	2352	December	3152	0	746	4092
Tot kWh_{el}	**6428**	**11028**	**5906**	**25933**	**Tot kWh_{el}**	**18129**	**5182**	**8783**	**34374**
kWh_{el}/m^2	**20**	**34**	**18**	**79**	**kWh_{el}/m^2**	**60**	**17**	**29**	**114**
$kWh_{primary}/m^2$	**39**	**66**	**35**	**154**	**$kWh_{primary}/m^2$**	**117**	**33**	**57**	**222**

According to the proposed results, it can be noted a very interesting outcome. Indeed, it is confirmed that lightweight structures, with lower U_{values} for the walls, have better energy performances in winter, while massive building envelopes (this is the case of the Italian ancient villa) better attenuate, compared to the lightweight technologies of concrete and hollow bricks, the heat wave in summer, with consequent lower energy demands for cooling. Anyway, it should be noted that the climate of Athens (modern house) is a little bit warmer both in winter and in summer compared to the one of Naples (Italy).

Finally, the following summarized results have been achieved, in terms of primary energy demands:

a) LIGHTWEIGHT HOUSE IN GREECE: space heating (EP_H) = 39 kWh/m²a, space cooling (EP_C) = 66 kWh/m²a, lighting (EP_L) = 35 kWh/m²a, total building electric uses (EP_{EE}) = 154 kWh/m²a, global cost over a 30 years' period (GC) = 301 €/m².
b) MASSIVE VILLA IN ITALY: space heating (EP_H) = 117 kWh/m²a, space cooling (EP_C) = 33 kWh/m²a, lighting (EP_L) = 57 kWh/m²a, total building electric uses (EP_{EE}) = 222 kWh/m²a, global cost over a 30 years' period (GC) = 480 €/m².

4. Optimization of the buildings energy retrofits

Aiming at improving building energy performances, an optimization process is conducted by means of coupling the BPS tool EnergyPlus and the optimization engine MATLAB®. More in detail, MATLAB® optimization toolbox permits to launch automatically EnergyPlus simulations and to manage their outputs, until the optimization process ends by satisfying a termination criterion. In our case, the optimization algorithm used is a genetic one (GA), properly derived by a non-dominated sorting genetic algorithm (NSGA-II). The following parameters are considered to set the algorithm (partly as in [10]): crossover fraction = 0.6, mutation fraction = 0.1, population size = 4·number of variables; elite count = 2, generations limit = 50. An ".idf" file (input for EnergyPlus) is properly parametrized, by considering a different parameter for each possible energy retrofit measure taken into account – namely, for each of the variables. By means of this parametrized .idf file, MATLAB® optimization toolbox is allowed to run an EnergyPlus simulation. In detail, a new .idf file is created, by copying the parametrized one and substituting each parameter with a proper value. Obviously, every simulation is characterized by a different combination of parameters' values. Finally, to run the dynamic energy simulation, a proper ".epw" weather file - available at the EnergyPlus online database – is needed.

About the performed optimization of our cases' studies, for minimizing, at the best, both building primary energy consumption (PEC) and global cost (GC), nine possible different energy retrofit measures are taken into account and these are codified as variables to be managed by the optimization logic. Those latter and their variability ranges – partly taken from previous studies [14] – are indicated in Table 4, Table 5 and Table 6, whilst in Table 7 are reported the investment costs necessary to realize each of the refurbish interventions proposed. These costs are taken from suppliers' quotations and from previous studies [14].

Table 4. Characterization of the design variables

DESIGN VARIABLES	VALUES
Additional insulation thickness of the roof [m]	0 (BB); 0.02; 0.04; 0.06; 0.08; 0.09; 0.10; 0.12
Additional insulation thickness of the vertical walls [m]	0 (BB); 0.02; 0.04; 0.06; 0.08; 0.09; 0.10; 0.12
Cool roof [-]	0=No (BB); 1=Yes
Type of windows [-]	1 (BB); 2; 3; 4 (see Table 5)
Type of shading systems [-]	0 (BB); 1; 2; 3; 4; 5; 6; (see Table 6)
Position of the shading systems [-]	1=Internal; 2=External
Improved HVAC system [-]	0=No (BB); 1=Yes [COP=3.8; EER=3.6]
Percentage of photovoltaic panels [%]	0 (BB); 25; 50; 75
Type of photovoltaic panels [-]	1=Polycrystalline; 2=Monocrystalline

Table 5. Investigated windows type

N°	TYPE	U [W/m²K]	SHGC [-]
1	Single glazed. Wood frame (BB)	5.90	0.86
2	Double-glazed with air-filling and low-e coating. PVC frame	2.12	0.69
3	Double-glazed with argon-filling and low-e coating. PVC frame	1.90	0.69
4	Selective double-glazed with air-filling and low-e coating. PVC frame	1.84	0.43

Table 6. Investigated shading systems

N°	TYPE	Solar Transmittance	Solar Reflectance	Visible Transmittance	Visible Reflectance
0	Shading system is absent (BB)	/	/	/	/
1	Manual Low reflect – Medium trans shade	0.4	0.2	0.4	0.2
2	Manual Medium reflect – Medium trans shade	0.4	0.5	0.4	0.5
3	Manual High reflect – Low trans shade	0.1	0.8	0.1	0.8
4	Domotic Low reflect – Medium trans shade	0.4	0.2	0.4	0.2
5	Domotic Medium reflect – Medium trans shade	0.4	0.5	0.4	0.5
6	Domotic High reflect – Low trans shade	0.1	0.8	0.1	0.8

Regarding the GC, this is evaluated considering a long-time period τ of 30 years, with the following equation, as established by EU Guidelines [15]:

$$GC(\tau) = IC + \sum_j \left[\sum_i^{\tau}(RC(i) * R_d(i) - V_{f,\tau}(j)\right] - IN \quad (1)$$

Where "IC" indicates the initial investment cost, "RC" stands for the annual running cost, actualized for each year of the evaluating period by means of R_d (actualization factor), "$V_{f,\tau}$" is the residual value at the end of the evaluation period, using a discount rate equal to 3%, "IN" states for the incentives applied on the initial investment cost. Because of the variability of the incentives due to different national policies, in this paper two different optimization scenarios are considered. Once no incentives are applied for the evaluation of GC, once a generic incentive of 50% of the investment cost is considered for every energy retrofit measure to be realized (with the exception of the realization of the cool roof). In order to give a complete overview of the obtained results, the optimization results are presented schematically in the following tables (see Table 8, Table 9, Table 10, Table 11).

Different budget limits are examined and, for each one, two different solutions are provided:

- the "nZEB solution", which is the solution on the Pareto front that reduces the most the PEC;
- the "cost-optimal solution", which is the solution on the Pareto front that reduces the most the GC.

Table 7. Investment costs of energy retrofit measures

ENVELOPE		
Energy efficiency measure	**Investment Cost Greece [€/m²]**	**Investment Cost Italy [€/m²]**
Roof additional insulation layer	22 + 3 · thickness (cm) of added layer	24 + 3 · thickness (cm) of added layer
Vertical walls additional insulation layer	38 + 3 · thickness (cm) of added layer	30 + 3 · thickness (cm) of added layer
Energy efficiency measure	**Characterization**	**Investment Cost [€/m²]**
Cool roof	/	25
Replacement of windows	Double-glazed with air-filling and low-e coating. PVC frame	250
	Double-glazed with argon-filling and low-e coating. PVC frame	280
	Selective double-glazed with air-filling and low-e coating. PVC frame	300
Installation of shading systems	Manual shading systems	80 · $A_{windows}$ * [€]
	Automatic shading systems	600 + 120 · $A_{windows}$ * [€]
HVAC SYSTEM + RES		
Energy efficiency measure	**Characterization**	**Investment Cost [€/m²]**
Replacement of the HVAC system	Improved reversible air-source electric heat pump	90
Installation of PV panels	Polycrystalline PV panels	250
	Monocrystalline PV panels	430

* *$A_{windows}$ stands for the extension of the windows' surface, not including the north façade*

Reducing the retrofit budget, the extension of the solutions' domain obviously decreases, and so on the Pareto front, thus the obtained results in terms of variation of PEC and GC – variation compared to the baseline situation – are much closer for the two optimal solutions considered for each retrofit budget. In this specific case, the nZEB solution changes by reducing the retrofit budget, whilst the cost-optimal one still remains the same. This partly happens because of the absence of the incentivisation, making the IC playing a really important role on the evaluation of the GC.

As it can be seen by the outcomes, shading systems are not taken into account in any of the optimal solutions found for both case studies, because of their costs – and so because of their fundamental role in determining the GC – and their reduced effects on PEC. Obviously, if it was considered the indoor thermal discomfort as objective function, they would have played a much more relevant role. On the contrary, PV panels are fundamental for both the climates, aiming at reducing PEC and GC, even in absence of funding incentives.

Table 8. Modern house retrofit in Greece – without incentives

MODERN HOUSE IN GREECE (climate of Athens) – NO INCENTIVES

Budget [€/m²]	Solution	Additional insulation layer roof [m]	Additional insulation layer vertical walls [m]	Cool roof [-]	Window type* [-]	Shading system type [-]	Shading system position [-]	Improved HVAC [-]	PV percentage [-]	PV type (M=Mono; P=Poly) [-]	Investment cost [€/m²]	Results: PEC variation** [kWh/m²a]	Results: GC variation** [€/m²]
Unlimited	nZEB	0.12	0.02	Yes	4	Absent	/	Yes	75 %	M	406	-97	164
	Cost-optimal	Absent	Absent	No	1 (original)	Absent	/	Yes	75 %	P	135	-79	-40
400	nZEB	0.10	0.02	Yes	4	Absent	/	Yes	75%	M	397	-96	156
	Cost-optimal	Absent	Absent	No	1 (original)	Absent	/	Yes	75 %	P	135	-79	-40
350	nZEB	0.06	Absent	Yes	4	Absent	/	Yes	75 %	P	334	-94	111
	Cost-optimal	Absent	Absent	No	1 (original)	Absent	/	Yes	75 %	P	135	-79	-40
250	nZEB	Absent	Absent	No	4	Absent	/	Yes	75%	P	238	-89	41
	Cost-optimal	Absent	Absent	No	1 (original))	Absent	/	Yes	75 %	P	135	-79	-40

** Window type's number refers to Table 5*

*** PEC variation and GC variation indicate the variation respect the baseline situation, without any retrofit intervention*

Table 9. Modern house retrofit in Greece – with incentives

MODERN HOUSE IN GREECE (climate of Athens) – WITH INCENTIVES

Budget [€/m²]	Solution	Additional insulation layer roof [m]	Additional insulation layer vertical walls [m]	Cool roof [-]	Window type* [-]	Shading system type [-]	Shading system position [-]	Improved HVAC [-]	PV percentage [-]	PV type (M=Mono; P=Poly) [-]	Investment cost [€/m²]	Results: PEC variation** [kWh/m²a]	Results: GC variation** [€/m²]
Unlimited	nZEB	0.12	0.02	Yes	4	Absent	/	Yes	75 %	M	406	-97	-10
	Cost-optimal	Absent	Absent	Yes	4	Absent	/	Yes	75 %	P	251	-90	-58
400	nZEB	0.12	Absent	Yes	4	Absent	/	Yes	75%	M	393	-96	-15
	Cost-optimal	Absent	Absent	Yes	4	Absent	/	Yes	75 %	P	251	-90	-58
350	nZEB	0.09	Absent	Yes	4	Absent	/	Yes	75 %	P	347	-95	-27
	Cost-optimal	Absent	Absent	Yes	4	Absent	/	Yes	75 %	P	251	-90	-58
250	nZEB	Absent	Absent	No	4	Absent	/	Yes	75%	P	238	-89	-61
	Cost-optimal	Absent	Absent	No	4	Absent	/	Yes	75%	P	238	-89	-61

** Window type's number refers to Table 5*

*** PEC variation and GC variation indicate the variation compared to the baseline situation, without any retrofit intervention*

All solutions – with the exception of one – provide the installation of PV panels on the 75% of the roof area (the maximum value of the range assumable by this variable), whilst the other one provides photovoltaics on the 50% of the roof area. By varying the retrofit budget, it changes only the typology of PV panels to be used (i.e., by reducing the budget monocrystalline panels are substituted by polycrystalline ones, which are less efficient, but cheaper). Keeping looking at the results, in most of the cases, single-glazed windows with wood frames need to be substituted with selective double-glazed with air-filling, low-e coating and PVC frames ones, whilst more rarely the present systems are replaced with simple double-glazed with air-filling ones (only in few optimal solutions, for the Italian Villa). In addition, aiming at producing a strong decrement of the PEC, in every of the optimal solutions found, it results crucial to improve the HVAC system, resulting the most cost-effective intervention too to be realized.

Table 10. Ancient villa retrofit in Italy – with no incentives

ANCIENT VILLA IN ITALY (climate of Naples) – NO INCENTIVES

Budget [€/m²]	Solution	Additional insulation layer roof [m]	Additional insulation layer vertical walls [m]	Cool roof [-]	Window type* [-]	Shading system type [-]	Shading system position [-]	Improved HVAC [-]	PPV percentage [-]	PPV type (M=Mono; P=Poly) [-]	Investment cost [€/m²]	Results	
												PEC variation** [kWh/m²a]	GC variation** [€/m²]
Unlimited	nZEB	0.12	0.12	Yes	4	Absent	/	Yes	75 %	M	314	-126	25
	Cost-optimal	0.06	Absent	No	2	Absent	/	Yes	75 %	P	230	-118	-40
300	nZEB	0.12	0.04	No	4	Absent	/	Yes	75%	M	298	-125	12
	Cost-optimal	0.06	Absent	No	2	Absent	/	Yes	75 %	P	230	-118	-40
250	nZEB	0.08	Absent	Yes	4	Absent	/	Yes	75 %	P	246	-120	-29
	Cost-optimal	0.06	Absent	No	2	Absent	/	Yes	75 %	P	230	-118	-40
200	nZEB	0.04	Absent	Yes	1 (original)	Absent	/	Yes	75%	P	192	-108	-54
	Cost-optimal	0.04	Absent	Yes	1 (original)	Absent	/	Yes	75%	P	192	-108	-54

** Window type's number refers to Table 5*

*** PEC variation and GC variation indicate the variation respect the baseline situation, without any retrofit intervention*

Table 11. Ancient villa retrofit in Italy – with incentives

ANCIENT VILLA IN ITALY (climate of Naples) – WITH INCENTIVES

Budget [€/m²]	Solution	Additional insulation layer roof [m]	Additional insulation layer vertical walls [m]	Cool roof [-]	Window type* [-]	Shading system type [-]	Shading system position [-]	Improved HVAC [-]	PPV percentage [-]	PPV type (M=Mono; P=Poly) [-]	Investment cost [€/m²]	Results	
												PEC variation** [kWh/m²a]	GC variation** [€/m²]
Unlimited	nZEB	0.12	0.12	Yes	4	Absent	/	Yes	75 %	M	314	-126	-122
	Cost-optimal	0.09	Absent	No	4	Absent	/	Yes	75 %	M	273	-123	-136
300	nZEB	0.12	0.04	No	4	Absent	/	Yes	75%	M	298	-125	-129
	Cost-optimal	0.09	Absent	No	4	Absent	/	Yes	75 %	M	273	-123	-136
250	nZEB	0.10	Absent	No	4	Absent	/	Yes	50 %	P	245	-113	-123
	Cost-optimal	0.04	Absent	No	4	Absent	/	Yes	75 %	P	228	-117	-143
200	nZEB	Absent	Absent	Yes	2	Absent	/	Yes	75%	M	188	-105	-133
	Cost-optimal	Absent	Absent	Yes	2	Absent	/	Yes	75%	M	188	-105	-133

** Window type's number refers to Table 5 ** PEC variation and GC variation indicate the variation respect the baseline situation, without any retrofit intervention*

Finally, the use of an additional insulation layer for the vertical walls is not optimal in most of the cases, because of its cost, higher than many other possible interventions. On the contrary, the additional insulation layer on the roof is much more effective, because of its lower cost – due to the reduced extension of the application surface and to the absence of cost for scaffolding.

5. Conclusions

With the aim to improve energy performances of dwellings on the coastline of Mediterranean regions, for minimizing both primary energy consumption (and so, polluting emissions connected to it) and operating costs (more precisely, the global cost, which includes running costs and initial investment for the retrofit), an optimization methodology that couples transient energy simulations (EnergyPlus) and optimization logic (MATLAB ®, genetic algorithm) is here proposed. This methodology is applied to two buildings, which are characterized by different construction technologies and ubication. Different optimization scenarios are considered, and different retrofit budgets are taken into account. Results show that, in general, all optimal solutions provide the use of more efficient HVAC systems, besides the installation of PV panels on almost all the useful area of the roof, so that these two interventions can be considered the most cost-effective ones among all the possible considered retrofit measures. This means that, nowadays, in sunny and warm climates as in Greece or South Italy, traditional energy retrofitting interventions on the envelope – by using additional layers of insulation or by realizing cool roofs – have to be effectively coupled to the exploitation of renewable energy sources or to the use of more modern HVAC systems, and, for this reason, those latter should be absolutely kept incentivized by local Governments.

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