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Energy Procedia 82 (2015) 855 – 862

Energy Procedia

ATI 2015 - 70th Conference of the ATI Engineering Association

Analysis of energy performance improvements in Italian residential buildings

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Abstract

Residential buildings represent the major energy consumers in Italy, it is therefore worthwhile to analyze existing buildings highlighting the best technologies, strategies and interventions for improving their energy efficiency.
In this context, this research gives particular attention to energy requirements related to winter heating, assessing the current energy demand of a building prototype having structural and plant standards assumed. Starting from the obtained energy efficiency data of the same building prototype in ten Italian pilot cities with different climate conditions and different wall structures, the aim of the paper is to assess the economic costs and the benefits in terms of optimization of the building energy performance indicator in the heating season (EPH in kWh/m^2 year) for the most common renovation interventions, in order to get a cost /benefits analysis for each intervention in each city. Therefore the paper provides data to establish a hierarchy of priorities regarding possible interventions on building envelope or plants. The proposed energy requalification interventions have been defined considering the use of standard packages of the vertical and horizontal structures of the envelope as well as the application of new plant technologies. In particular, the parameters used for the characteristics of the interventions have been selected following the specified UNI-TS 11300 1-2008 and schedules provided by the Italian Thermo-Technical Committee (CTI).The obtained results could be useful to highlight the most convenient solutions for improving energy efficiency for each analyzed Italian city.

Peer-review under responsibility of the Scientific Committee of ATI 2015

Keywords: Building energy performances; costs benefits analysis; energy efficiency;

1. Introduction

Climate is undoubtedly one of the main factors which influence the energy demand for space heating. Of course, in environments with harsh climate, energy performances of buildings casing and plant should

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Peer-review under responsibility of the Scientific Committee of ATI 2015
doi:10.1016/j.egypro.2015.11.826

be higher than in areas with milder climates. According with the national rules (Legislative Decree 311/2006), the Italian municipalities are classified into six climate zones (A, B, C, D, E, F), depending on their degree-days (D.D), expressed as the annual sum of the daily differences, between the conventional temperature attributed to the internal environment (20° C for residential buildings) and the average daily outdoor temperature, considering only the period when heating system are allowed to work. Consequentially, heating energy demands of each building is a function of the degree days of its location [1]. Starting from these consideration, the main objective of the paper is to assess the energy performance indicator in the heating season (EPH) of a pilot building in different climate conditions, taking into account ten Italian cities characterized by different degree-day values and different wall structures.

Moreover, since most of the existing buildings in Italy are characterized by inadequate energy performance indicators, the paper foreseen an analysis of the EPH optimization in each considered city, considering the most common renovation interventions with the appropriate technologies for improving the energy efficiency of a building [2-4] . The obtained results have been then compared with an assessment of the economic costs for each considered intervention in order to get a simple cost / benefits analysis. The final results could be useful for the planning of requalification interventions in Italian residential buildings.

2. Methods

The first step of the methodology foreseen the choice of a pilot building where to simulate its energy performances in ten pilot Italian cities selected according to a difference of about 200 degrees-day from each other. As a building type was chosen a building that falls within the types of construction of the '60s, corresponding to the period of the residential construction boom in Italy. The building is composed by 4 floors with a regular shape, surface area of 1.233 square meters and a volume of 3.787 cubic meters; moreover the building roof is not practicable, the basement is unheated and all the windows have simple glasses. The shape factor of the building is 0.33, calculated as the surface/volume ratio. The wall structure of the pilot building varies in each selected city according to the most common packages used in the 60s, in each Italian region. After determining the geometric characteristics of the pilot building in each one of the ten cities, thermal transmittances (U)(Table 1) and energy performances (Table 2) have been evaluated. Energy performances have been calculated using STIMA 10 software. All the parameters for each city were derived from the intersection of degree-days and UNITS 11300 data, as well as the schedules provided by the Italian Thermo-Technical Committee (CTI). Through the Energy Performance Certificate (EPAs), made on the case studies, have been extrapolated the envelop energy needs for heating (Q_{nh}) considering only the envelope, and the total energy needs(q_{gh}) values, which include also the plant.

Table 1 thermal transmittances (U) in(W/m²k of the pilot buildings in the ten analyzed cities

City	Climate zone	D.D.	U walls	U roof	U floor on the ground	U windows
Salerno	C	994	0.76	1.5	1.25	5.3
Napoli	C	1034	0.76	1.5	1.25	5.3
Roma	D	1415	2	1.5	1.25	5.3
Prato	E	1668	1.38	1.5	1.25	5.3
Pistoia	D	1885	1.38	1.5	1.25	5.3
Rimini	E	2139	0.77	1.5	1.25	5.3
Ravenna	E	2227	0.77	1.5	1.25	5.3
L'aquila	E	2514	2	1.5	1.5	5.3
Lodi	E	2592	1.51	1.5	1.25	5.3
Sondrio	E	2755	1.51	1.5	1.25	5.3

Table 2Energy performance of the pilot buildings in the ten analyzed cities

City / Climate zone	Qnh (kWh)	Qgh (kWh)	EPH/ Energetic class (kWh/m² yr)
Salerno / C	88550	115322	93.6 / F
Napoli/ C	81151	112078	90.9 / F
Roma/ D	155006	218365	177.2 / G
Prato/ E	172369	230895	187.3 / G
Pistoia/ D	179751	235437	191 / G
Rimini/ E	175983	230841	187.3 / F
Ravenna/ E	193094	249794	202 / F
L'Aquila/ E	247920	349512	283.6 / G
Lodi/ E	247400	329664	267.5/ G
Sondrio/ E	219720	314259	255 / G

Consequentially have been estimated the energy efficiency improvements resulting from the four most common interventions on the envelope: replacing windows, opaque vertical wall, roof or floor on ground isolations; the energy efficiency improvement of these intervention has been estimated using the transmittance limits of the national rule for each climate zone Legislative Decree 311/2006 (Table 3).To get these U values, horizontal and vertical opaque structures have been considered as equipped with insulation, while for windows values fixtures have been considered replaced by new ones with double glazing. These interventions were evaluated both individually and cumulative to better appreciate their performance in terms of energy efficiency.

Table 3 Transmittance limits in (W/m^{2}k) for each climate zone according with the Italian Legislative Decree 311/2006

Climate zone	U opaque vertical wall	U roof	U floor on the ground	U windows
A	0.54	0.32	0.6	3.7
B	0.41	0.32	0.46	2.4
C	0.34	0.32	0.4	2.1
D	0.29	0.26	0.34	2
E	0.34	0.24	0.3	1.8
F	0.26	0.23	0.28	1.6

Considering the pilot building system has been hypothesized a centralized system consists of a boiler burner standard with two stars, with a thermal output of 102 kW rated output assumed; each climate zone has provided the daily hours and the period when the system could work according to national rules. Regarding the emission systems were chosen not isolated radiators with a manual type regulation. Subsequently plant typologies were considered for possible replacements with three higher efficiency typologies: biomass boiler, condensing boiler with 4 stars burner and a high-efficiency heat pump. The emission system has been improved through the use of thermostatic valves with manual control on the radiators.

3. Results

Tables 4 and 5 summarize the results obtained applying the described interventions in the pilot buildings for each considered city, while table 6 relates the estimation of the economic costs for each considered intervention, both on the building envelope and system plant, considering average values obtained from an analysis of the prices of two companies for each Italian region.

Table 4 Energy efficiency data after for each intervention on the building envelope

City / Climate zone	Replacing fixtures				Opaque vertical wall isolation				Floor on ground isolation			
	Qnh (kWh)	Qgh (kWh)	EPH/ Energetic class (kWh/m²yr)	EPH improvement (%)	Qnh (kWh)	Qgh (kWh)	EPH/ Energetic class (kWh/m²yr)	EPH variation (%)	Qnh (kWh)	Qgh (kWh)	EPH/ Energetic class (kWh/m²yr)	EPH variation (%)
Salerno C	76774	95502	77.5 F	17.2	77361	93754	76.1 F	18.6	87304	108832	88.3 F	5.6
Napoli C	69080	90911	73.8 F	18.8	70042	89751	72.8 F	19.9	79883	105682	85.7 F	5.7
Roma D	106102	145218	117.8 F	33.5	104028	139337	113 F	36.2	134506	187125	151.8 G	14.3
Prato E	136053	177940	144 G	23.1	132713	170077	138 G	26.3	150600	197253	160 G	14.5
Pistoia D	142089	181698	174 G	8.9	138708	174068	141.2 F	26	177088	231914	188.2 G	1.4
Rimini E	174908	225576	183 F	2.2	154054	198373	160.9 E	14	175983	221001	179.3 F	4.2
Ravenna E	159033	208278	169 E	16.3	169257	214747	174.2 F	13.7	189371	244833	198.6 F	1.6
L'Aquila E	221453	293564	238.2 G	16	161558	204101	165.6 F	41	244041	329228	267.1 G	5.8
Lodi E	245111	315818	256.2 G	4.2	181258	215887	175.2 G	34.5	243346	310055	251.6 G	5.9
Sondrio E	214678	298908	242.5 G	4.9	156482	208622	169.3 F	33.6	215447	295450	239.7 G	6

continue Table 4

City/ Climate zone	Roof isolation				Sum interventions on building envelope			
	Qnh (kWh)	Qgh (kWh)	EPH/ Energetic class (kWh/m²a)	EPH variation (%)	Qnh (kWh)	Qgh (kWh)	EPH/ Energetic class (kWh/m²a)	EPH variation (%)
Salerno C	75156	89717	72.8 F	22.2	58695	65411	53.1 E	43.2
Napoli C	67569	85865	69.7 E	23.3	51085	62485	50.7 D	44.2
Roma D	120239	164199	133.2 G	24.8	73453	93239	75.6 E	57.3
Prato E	130497	165506	134.3 G	28.2	94366	112777	91.5 E	51.1
Pistoia D	158681	204264	165.7 G	13.2	100515	122283	97.4 E	49
Rimini E	151581	193798	157.2 E	16	108171	133441	106.2 D	43.2
Ravenna E	166506	209802	170.2 F	15.7	119528	142727	115.8 D	42.6
L'Aquila E	213267	277942	225.5 G	20.4	115776	140275	113.8 E	59.8
Lodi E	235508	292114	237 G	11.4	132994	148886	120.8 E	54.8
Sondrio E	206610	283203	229.8 G	9.8	107953	140454	114 D	55.2

Table 5 Energy efficiency data after for each intervention on the plant system.

City / Climate zone	Condensing boilers				Biomass boiler				Heat pump			
	Qnh (kWh)	Qgh (kWh)	EPH/ En. class (kWh/ m²yr)	EPH improvement (%)	Qnh (kWh)	Qgh (kWh)	EPH/ En. class (kWh/ m²yr)	EPH improvement (%)	Qnh (kWh)	Qgh (kWh)	EPH/ En. class (kWh/ m²yr)	EPH improvement (%)
Salerno C	60699	65613	52.3 D	44.1	60699	88163	70.3 F	24.8	60699	41023	33.1 C	64.6
Napoli C	53147	57449	45.8 D	49.6	53147	77169	61.6 E	32.2	53147	36069	29.2 B	67.8
Roma D	73453	79800	63.6 D	57.3	73453	107227	85.5 E	51.7	73453	52696	42.5 C	76
Prato E	94366	102512	81.7 E	56.3	94366	137812	109.7 F	41.4	94366	70361	56.5 C	69.8
Pistoia D	100515	110363	87.9 E	53.9	100515	148385	118.1 F	38.1	100515	76687	61.5 C	67.8
Rimini E	108171	118769	94.5 D	51.1	108171	159680	127.1 D	32.1	108171	85654	68.7 C	63.3
Ravenna E	119528	131239	140.5 D	30.4	119528	176473	140.4 E	30.4	119528	97821	78.3 C	61.2
L'AquilaE	119802	130879	104.3 E	63.1	119802	175988	140.0 F	50.6	119802	97269	77.9 D	72.5
Lodi E	137076	149749	119.3 E	55.4	137076	201401	160.1 F	40.1	137076	114139	91.3 D	65.8
Sondrio E	112186	122558	97.5 D	61.76	112186	164783	131.1 E	48.5	112186	95244	76.3 C	70

Table 6 Estimation of economic costs of each considered envelope or system intervention in Italy

Interventions	Cost per square meter (€/m²)	Intervention price (€)	Area (m²)	Total price (€)
Double glass windows	35		222.48	7786.80
Opaque vertical wall isolation	20		900.32	18006.4
Floor on ground isolation	24		373.1	8954.4
Roof isolation	35		373.1	13058.5
Total price interventions on building envelope				95612.2
Heat pump		50000		50000
Biomass boiler		20000		20000
Condensing boilers		25000		25000

Integrating the above results, it was possible to elaborate a costs / benefits analysis for each considered intervention, highlighting for each cities the cost for an EPH improvement of 1 kWh/m^2 year both for building envelope interventions (Table 7) as well as for plant interventions (Table 8).

Table 7 Estimation of economic costs for improvement EPHC of 1 kWh/m^2 year with building envelope interventions

City	Replacing fixtures			Opaque vertical wall isolation			Floor on ground isolation		
	Total price (€)	EPH improvement (kWh/m²yr)	Cost for improvement EPH of 1 kWh/m²yr (€)	Total price (€)	EPH improvement (kWh/m²yr)	Cost for improvement EPH of 1 kWh/m²yr (€)	Total price (€)	EPH improvement kWh/m²yr)	Cost for improvement EPH of 1 kWh/m²yr (€)
Salerno	7786.80	16.1	483.65	18006.4	17.5	1028.94	8954.4	5.3	1689.51
Napoli	7786.80	17.1	455.37	18006.4	18.1	994.83	8954.4	5.2	1722.00
Roma	7786.80	59.4	131.09	18006.4	64.2	280.47	8954.4	25.4	352.54
Prato	7786.80	43.3	179.83	18006.4	49.3	365.24	8954.4	27.3	328.00
Pistoia	7786.80	17	458.05	18006.4	49.8	361.57	8954.4	2.8	3198.00
Rimini	7786.80	4.3	1810.88	18006.4	26.4	682.06	8954.4	8	1119.30
Ravenna	7786.80	33	235.96	18006.4	27.8	647.71	8954.4	3.4	2633.65
L'Aquila	7786.80	45.4	171.52	18006.4	118	152.60	8954.4	16.5	542.69
Lodi	7786.80	11.3	689.10	18006.4	92.3	195.09	8954.4	15.9	563.17
Sondrio	7786.80	12.5	622.94	18006.4	85.7	210.11	8954.4	15.3	585.25

continue Table 7

City	Roof isolation			Sum interventions on building envelope		
	Total price (€)	EPH improvement (kWh/m²yr)	Cost for improvement EPH of 1 kWh/m²yr (€)	Total price (€)	EPH improvement (kWh/m²yr)	Cost for improvement EPH of 1 kWh/m²yr (€)
Salerno	13058.5	20.8	627.81	95612.2	60	1593.54
Napoli	13058.5	21.2	615.97	95612.2	62	1542.13
Roma	13058.5	44	296.78	95612.2	193	495.40
Prato	13058.5	53	246.39	95612.2	173	552.67
Pistoia	13058.5	25.3	516.15	95612.2	95	1006.44
Rimini	13058.5	30.1	433.84	95612.2	69	1385.68
Ravenna	13058.5	31.8	410.64	95612.2	96	995.96
L'Aquila	13058.5	158.1	82.60	95612.2	338	282.88
Lodi	13058.5	30.5	428.15	95612.2	150	637.41
Sondrio	13058.5	25.2	518.19	95612.2	139	687.86

Table 8 Estimation of economic costs for improvement EPHC of 1 kWh/m^2 year with plant system substitution

City	Condensing boilers			Biomass boiler			Heat pump		
	Total price (€)	EPH improvemen t (kWh/m²yr)	Cost for improvemen t EPH of 1 kWh/m²yr (€)	Total price (€)	EPH improvemen t kWh/m²yr)	Cost for improvemen t EPH of 1 kWh/m²yr (€)	Total price (€)	EPH improvemen t kWh/m²yr)	Cost for improvemen t EPH of 1 kWh/m²yr (€)
Salerno	2500 0	41.3	605.33	2000 0	23.3	858.37	5000 0	60.5	826.45
Napoli	2500 0	45.1	554.32	2000 0	29.3	682.59	5000 0	61.7	810.37
Roma	2500 0	113.6	220.07	2000 0	91.7	218.10	5000 0	134.7	371.20
Prato	2500 0	105.6	236.74	2000 0	77.6	257.73	5000 0	130.8	382.26
Pistoia	2500 0	103.1	242.48	2000 0	72.9	274.35	5000 0	129.5	386.10
Rimini	2500 0	92.8	269.40	2000 0	60.2	332.23	5000 0	118.6	421.59
Ravenn a	2500 0	61.5	406.50	2000 0	61.6	324.68	5000 0	123.7	404.20
L'Aquil a	2500 0	179.3	139.43	2000 0	143.6	139.28	5000 0	205.7	243.07
Lodi	2500 0	148.2	168.69	2000 0	107.4	186.22	5000 0	176.2	283.77
Sondrio	2500 0	157.5	158.73	2000 0	123.9	161.42	5000 0	178.7	279.80

4. Discussions and conclusions

Comparing the analysis of the proposed intervention in each city, it is evident that the energy performance improvement varies according to the considered city, in relation with its degree-days and the considered building wall packages. Considering building envelope interventions, the obtained results underline a significant difference of Cost for improvement EPH of 1 kWh/m²year (€) among cities. Moreover comparing the four considered interventions it is possible to see that generally roof isolation is the one with minor costs for improvement EPH of 1 kWh/m²year while floor on ground isolation is the most expensive. Conversely, according with the official national data most of the interventions in Italy are carried out on fixtures, second on the walls, denoting that the choices are generally made on the basis of other considerations that do not refer to economic benefits nor to choices aimed at improving energy efficiency. Analysing plant systems substitution data it is possible to that the cost for improvement EPH of 1 kWh/m²year (€) is generally low in cities with a higher value of degree-days. Finally, the obtained results could be useful as simple overview of the current situation of residential building as well as to understand what type of approach the planners should take to intervene in existing building for a sustainable management of urban areas [5-6] considering cost /benefit analysis.

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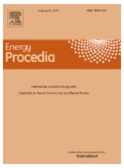

Biography

Elisa Carbonara is an architect and a PhD Student in "Energy and Environment", at Department of Astronautical, Electrical and Energy Engineering (DIAEE) of the Sapienza University of Rome. Her researches are mainly focused on renewable energy sources and energy analysis of residential sector.