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# 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.


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## 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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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/m$^2$yr) | EPH improvement (%) | Qnh (kWh) | Qgh (kWh) | EPH/ Energetic class (kWh/m$^2$yr) | EPH variation (%) | Qnh (kWh) | Qgh (kWh) | EPH/ Energetic class (kWh/m$^2$yr) | 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/m$^2$a) | EPH variation (%) | Qnh (kWh) | Qgh (kWh) | EPH/ Energetic class (kWh/m$^2$a) | 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 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 | 25000 | 41.3 | 605.33 | 20000 | 23.3 | 858.37 | 50000 | 60.5 | 826.45 |
| Napoli | 25000 | 45.1 | 554.32 | 20000 | 29.3 | 682.59 | 50000 | 61.7 | 810.37 |
| Roma | 25000 | 113.6 | 220.07 | 20000 | 91.7 | 218.10 | 50000 | 134.7 | 371.20 |
| Prato | 25000 | 105.6 | 236.74 | 20000 | 77.6 | 257.73 | 50000 | 130.8 | 382.26 |
| Pistoia | 25000 | 103.1 | 242.48 | 20000 | 72.9 | 274.35 | 50000 | 129.5 | 386.10 |
| Rimini | 25000 | 92.8 | 269.40 | 20000 | 60.2 | 332.23 | 50000 | 118.6 | 421.59 |
| Ravenna | 25000 | 61.5 | 406.50 | 20000 | 61.6 | 324.68 | 50000 | 123.7 | 404.20 |
| L'Aquila | 25000 | 179.3 | 139.43 | 20000 | 143.6 | 139.28 | 50000 | 205.7 | 243.07 |
| Lodi | 25000 | 148.2 | 168.69 | 20000 | 107.4 | 186.22 | 50000 | 176.2 | 283.77 |
| Sondrio | 25000 | 157.5 | 158.73 | 20000 | 123.9 | 161.42 | 50000 | 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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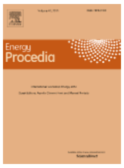


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