Both the case studies belong to the construction period ranging from 1946 to 1976. The main geometric data do not differ across the climatic zones (see Table 1).

2.2 Identification of the cost-optimal level of energy performance through a cost-optimisation procedure

The energy efficiency measures (EEMs) applied to each reference building have been defined by the Italian Ministry of Economic Development (2013) and by Corrado et al. (2013). An appropriate parameter is associated to each measure; e.g. the *U*-value for the thermal insulation of the building envelope, the heat generator efficiency (either η or *COP* or *EER*) for the technical systems replacement, the collectors area (A_{coll}) for the thermal solar system installation, the peak power (W_{PV}) for the photovoltaic system installation. For each measure, up to five energy efficiency options or levels (EEOs) are defined. The first level usually represents an inefficient solution used as a test value; the second level represents the requirement fixed by current legislation (Italian Government, 2005); the levels from the third to the fifth (if applicable) are more efficient solutions.

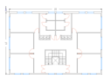
The initial investment cost associated to each EEO comes either from extensive market surveys or from official databases. The costs of the energy carriers are derived from the National Authority for Electricity and Natural Gas (AEEG), considering the rates applied for the enhanced protection service. The estimated energy carriers price development trends are those provided by the European Commission on a biannually updated basis (PRIMES model), according to Annex 2 of the Commission Delegated Regulation No. 244/2012 (European Union, 2012a). These trends have been extrapolated beyond 2030, which is the last year taken into account in the available projections.

Other input data and assumptions are detailed in the report of the Italian Ministry of Economic Development (2013) and in Corrado et al. (2013).

The energy performance is calculated according to the Italian technical specification UNI/TS 11300 (Italian Organisation for Standardisation, 2010-2014) and the global cost analysis is performed according to EN 15459 (European Committee for Standardization, 2007), considering an estimated economic lifetime of 30 years for the residential buildings and 20 years for the offices, a discount rate of 4%, and applying a financial cost optimum calculation.

The cost optimisation is carried out by means of a procedure based on a sequential search-optimisation technique considering discrete options, as described in Corrado et al. (2014). The optimal level of annual primary energy use for heating, cooling and domestic hot water, and the corresponding actualized global cost are shown in Table 2 for the selected reference buildings. The related optimal values of the design parameters are listed in Table 3.

Table 2 – Cost optimal level of the reference buildings

Reference Building	**Climatic Zone**	**EP [kWh m^{-2}]**	**Global cost [€ m^{-2}]**
 Residential	Milano (2404 HDD)	61.0	495
	Palermo (751 HDD)	36.6	384
 Office	Milano (2404 HDD)	86.9	781
	Palermo (751 HDD)	65.3	695

2.3 Description of the economic scenarios

Cost calculations and projections with many assumptions and uncertainties, including for example energy price developments over time, are generally accompanied by a sensitivity analysis to evaluate the robustness of the key input parameters. For the purpose of the cost-optimal calculations, the Regulation No. 244/2012 (European Union, 2012a) requires that the sensitivity analysis should at least address the discount rate and the energy price developments.

2.3.1 Discount rate scenario

The discount rate means a definite value for comparison of the value of money at different times

Table 3 – Optimal values of the energy efficiency measures for the analysed reference buildings

EEM		Optimal EEO			
		Residential / Milano	**Residential / Palermo**	**Office / Milano**	**Office / Palermo**
Wall insulation (on external surface)	U_{wl} [W m^{-2} K^{-1}]	-	-	-	-
or Wall insulation (on cavity)		0.34	0.48	0.20	0.44
Upper floor insulation	$U_{fl,up}$ [W m^{-2} K^{-1}]	0.40	0.50	0.27	0.38
Lower floor insulation	$U_{fl,lw}$ [W m^{-2} K^{-1}]	0.45	0.65	-	-
Windows	U_{w} [W m^{-2} K^{-1}]	1.60	3.00	1.60	3.00
Solar shading devices	τ_{sh} [-] / M *or* F (*)	0.4 / F	0.2 / F	0.4/F	0.2 / F
Heat generator for space heating	$\eta_{H,gn}$ [-] *or* COP [-]	-	-	-	-
+ Heat generator for domestic hot water	$\eta_{W,gn}$ [-]	-	-	-	-
+ Chiller	EER [-]	-	-	-	-
or Combined heat generator for space heating and domestic hot water	$\eta_{H,W,gn}$ [-]	-	-	0.93	0.93
+ Chiller	EER [-]	-	-	3.50	3.50
or Combined generator for heating, cooling and domestic hot water	COP [-]	4.20	4.20	-	-
	EER [-]	3.10	3.10	-	-
Thermal solar system	A_{coll} [m^2]	14	14	2	2
Photovoltaic system	W_{PV} [kW$_P$]	2	2	5	5
Ventilation heat recovery	NO *or* YES (η_{ru} [-])	NO	NO	YES (0.6)	YES (0.6)
Efficiency of the heat control system	η_{rg} [-]	0.995	0.995	0.97	0.97
Lighting power density(**)	W_{lgt} [W m^{-2}]	N/A	N/A	4.60	4.60
Lighting control system parameters(**)	F_O [-]	N/A	N/A	0.8	0.8
	F_C (F_D) [-]	N/A	N/A	0.9	0.9

(*) M = mobile louvres; F = fixed louvres.

(**) Not applicable (N/A) for the residential buildings.

expressed in real terms, hence excluding inflation. The global cost is directly linked to the duration of the calculation period t, as shown in Eq. (1). The calculation of the global cost $C_g(t)$ referred to the starting year t_0 may be performed by a component or system approach, considering the initial investment C_I, and, for every component or system j, the annual costs C_a and the discount factor $R_{disc}(i)$ for every year i (referred to the starting year), and the final value Val_F.

$$C_g(t) = C_I + \sum_j \left[\sum_{i=1}^{t} \left(C_{a,i}(j) \cdot R_{disc}(i) \right) - Val_{F,t}(j) \right] \quad (1)$$

The discount factor $R_{disc}(i)$, for every year i, is a multiplicative number used to convert a cash flow occurring at a given point in time to its equivalent value at the starting point. The discount factor is derived from the discount rate r and is calculated as:

$$R_{disc}(i) = \left(\frac{1}{1+\frac{r}{100}} \right)^i \quad (2)$$

where, i is the number of years from the starting period.

According to the Guidelines accompanying the Regulation (European Union, 2012b), a higher discount rate – typically higher than 4% excluding inflation – would reflect a purely commercial, short-term approach to the valuation of investments. A lower rate – typically ranging from 2% to 4% excluding inflation – would more closely reflect the benefits that energy efficiency invest ments bring to building occupants over the entire investment's lifetime.

The first economic scenario on the reference buildings consists in the variation of the discount rate, from 4% of the base scenario to 5%.

2.3.2 Energy price development scenario

The information provided in Annex 2 of the Regulation (European Union, 2012a) is taken from energy trend scenarios developed with the PRIMES model, i.e. a modelling system that simulates a market equilibrium solution for energy supply and demand in the EU27 and its Member States.

The baseline price assumptions for the EU27 are the result of world energy modelling (using the PROMETHEUS stochastic world energy model) that derives price trajectories for oil, gas and coal under a conventional wisdom view of the development of the world energy system.

The latest update (2009) implies a 2.8% annual increase in gas prices, a 2.8% annual increase in oil prices and a 2% annual increase in coal prices. As regards electricity, estimated long-term after-tax electricity price developments in €/MWh are shown in Table 4.

Table 4 – Estimated long-term after-tax electricity price developments (€/MWh; source: European Commission)

Sector	2000	2005	2010	2015	2020	2025	2030
Residential	127	133	144	164	180	191	192
Services	123	124	124	139	152	159	159

According to the Guidelines (European Union, 2012b), the trends of the energy prices may be extrapolated beyond 2030 until more long-term projections become available. In order to consider the whole estimated economic lifetime of the residential buildings and of the offices, the extrapolation is done up to 2050 (considering 2013 as the starting year).

Table 5 – Identification of price development scenarios of electricity (E) and/or natural gas (NG)

Scenario	E	NG	E and NG
50% lower annual estimated increment of price	I	III	V
50% higher annual estimated increment of price	II	IV	VI

Starting from the base scenario for each reference building, the second economic analysis consists in applying the scenarios listed in Table 5 to the energy trend of the Annex 2 of the Regulation.

For each of the scenarios listed in Table 5, a discount rate of 4% is applied. The energy price trends of the base scenario are shown in Fig. 1.

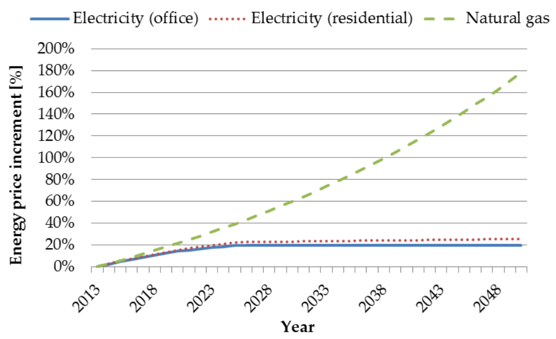


Fig. 1 – Base scenario energy price trends

3. Result analysis and discussion

The results of the economic scenarios on the reference buildings are shown in Figs. 2-3 for residential buildings and offices respectively, where "DR" stands for the variation of the discount rate, the roman numerals correspond to the cases in Table 5 and the lines represent the base scenario Cost Optimality trend for the two climatic zones considered. The results show the robustness of the residential buildings optimal EEM package, as the energy performance approximately keeps the value of 36.6 kWh m^{-2} in Palermo and of 61.0 kWh m^{-2} in Milano when different economic scenarios are applied. Concerning the economic aspects, as an effect of the financial calculation principle, the amount of global costs is lower when a higher discount rate is applied, but the deviation from the base scenario is only of 25 € m^{-2} in Palermo and of 31 € m^{-2} in Milano. By applying the different energy costs scenarios in Table 5 the global cost deviation in respect with the base scenario is not significant.

Concerning the offices in Palermo, the energy performance still approximately remains at the base scenario same value of 65.3 kWh m^{-2} when different economic scenarios are applied; the only relevant difference is shown for Milano, where the highest deviation between the DR and the base scenario is of 5.0 kWh m^{-2}, as the increasing discount rate involves a reduction of the EEMs optimal performance levels of the roof thermal insulation and of the photovoltaic system peak power installed. Other changes in the optimal level of the energy efficiency measures are shown for the offices in Milano, as follow: when the electricity cost increase is lower (scenario I) the optimal solution consists of the installation of a lower surface of PV panels; when the natural gas cost increase is lower (scenarios III and V) the optimal solution consists of lower roof thermal insulation as well as of PV system performance levels. Conversely, in Palermo when the natural gas cost increase is higher (scenarios IV and VI), the roof thermal insulation optimal level is higher.

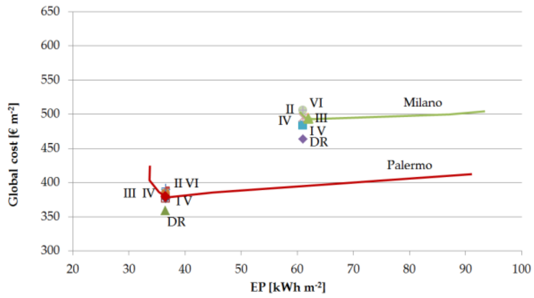


Fig. 2 – Residential Cost Optimal values for different economic scenarios

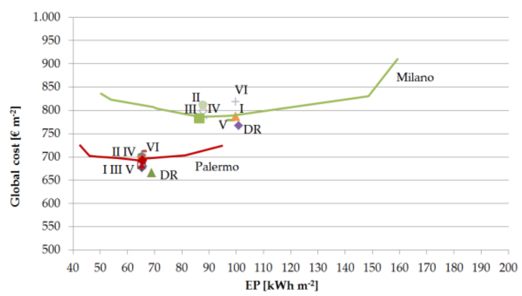


Fig. 3 – Office Cost Optimal values for different economic scenarios

Figs. 4-5 show the optimal global costs for the different economic scenarios mentioned above, for residential and office respectively, where "MI" stands for Milano and "PA" for Palermo. The energy costs are subdivided in investment, energy and operating & maintenance. With regard to the residential buildings, the investment costs are generally twice the amount of the energy costs and of the operating & maintenance costs; as the energy efficiency measures and levels do not change with the different economic scenarios, the investment costs remain fixed, while the operating & maintenance costs only change when the discount rate varies. In addition, the energy costs vary with the energy scenarios, but the highest deviation is lower than 25 € m^{-2} in Milano and 15 € m^{-2} in Palermo.

Concerning the offices, the energy costs are comparable with respect to the investment costs: in terms of energy costs the highest deviation corresponds to 50 € m^{-2} either for Milano (between III and VI scenarios) and Palermo (between DR and II scenarios), while deviations in investment costs never exceed the 15 € m^{-2}.

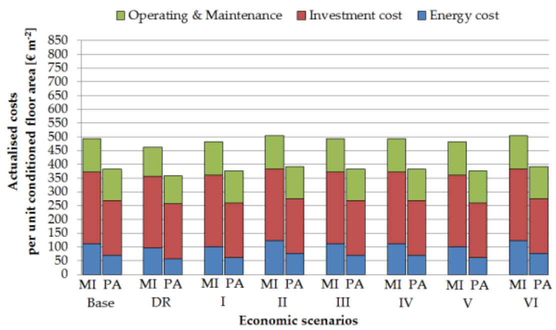


Fig. 4 – Residential Cost Optimal actualized costs for different economic scenarios

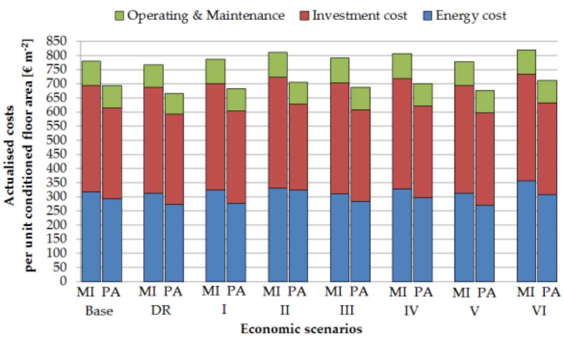


Fig. 5 – Office Cost Optimal actualized costs for different economic scenarios

4. Conclusion

In the present article different economic scenarios have been investigated in order to determine the influence of the discount rate and of the energy price trend on the cost optimal packages of EEMs and on the corresponding levels of building EP.

For some reference buildings different in use and location, it has been verified that the optimal level of energy efficiency usually corresponds to a set of design parameters consistent with the requirements fixed by the current legislation (Italian Government, 2005), which mainly concern the insulation-value of the vertical building enclosures.

Through the application of a sensitivity analysis in the cost optimisation procedure, the robustness of the optimal solutions of EEMs packages has been demonstrated, as both the discount rate and the energy price development variations have a weak influence on the cost optimal level of building energy performance and on the choice of the optimal energy efficiency measures (EEMs) package. This result is especially true in the case of residential buildings, as the weight of the investment costs is twice the amount of the energy costs and of the operating & maintenance costs.

A future analysis will consist in conducting additional sensitivity analyses for other cost drivers as identified in the calculation, for instance the initial investment cost of the building components. In this regard, a range of variation should be defined for each investment cost and the costs differentiated by climatic zone.

5. Acknowledgement

This work has been carried out within a cooperation agreement with ENEA (*Italian National agency for new technologies, Energy and sustainable economic development*) concerning the "*Development and updating of the cost optimal methodology for assessing the compliance of national energy standards according to Directive 2010/31/EU*".

6. Nomenclature

Symbols

A	area (m^2)
C	cost (€)
COP	coefficient of performance (-)
EEM	energy efficiency measure
EEO	energy efficiency option
EER	energy efficiency ratio (-)
EP	energy performance (kWh m^{-2})
F, R	factor (-)
r	rate (-)
U	thermal transmittance (Wm^{-2}K^{-1})
V	volume (m^3)
Val	value (€)
W	power (W)
η	efficiency (-)
τ	transmission coefficient (-)

Subscripts/Superscripts

a	annual
C	constant (illuminance)
coll	solar collectors
D	daylight
disc	discount
env	envelope
F	final
f	floor
fl,lw	lower floor
fl,up	upper floor
g	global, gross
gn	generation (system)
H	heating
I	investment
lgt	lighting
n	net
O	occupancy
PV	photovoltaic (system)
rg	control (system)
ru	heat recovery unit
sh	shading
W	domestic hot water
w	window
wl	wall (opaque)

References

Ascione, F., N. Bianco, C. De Stasio, G. M. Mauro, and G. P. Vanoli. 2015. "A new methodology for cost-optimal analysis by means of the multi-objective optimisation of building energy performance". *Energy and Buildings* 88: 78-90. doi: 10.1016/j.enbuild.2014.11.058.

Brandão de Vasconcelos, A., M. Duarte Pinheiro, A. Manso, and A. Cabaço. 2015. "A Portuguese approach to define reference buildings for cost-optimal methodologies". *Applied Energy* 140: 316-328. doi: 10.1016/j.apenergy.2014.11.035.

Corrado, Vincenzo, Ilaria Ballarini, Stefano Corgnati, and Novella Talà. 2011. *Building Typology Brochure – Italy. Fascicolo sulla Tipologia Edilizia Italiana*. Torino: Politecnico di Torino.

Corrado, Vincenzo, Ilaria Ballarini, and Simona Paduos. 2013. *Sviluppo della metodologia comparativa cost-optimal secondo Direttiva 2010/31/UE*. ENEA RdS/2013/144.

Corrado, V., I. Ballarini, and S. Paduos. 2014. "Assessment of cost-optimal energy performance requirements for the Italian residential building stock" *Energy Procedia* 45: 443-452. doi: 10.1016/j.egypro.2014.01.048.

European Committee for Standardization. 2007. EN 15459. Energy performance of buildings - Economic evaluation procedure for energy systems in buildings.

European Union. 2010. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast). Official Journal of the European Union, 18 June 2010.

European Union. 2012a. Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council. Official Journal of the European Union, 21 March 2012.

European Union. 2012b. Guidelines accompanying Commission Delegated Regulation (EU) No 244/2012 of 16 January 2012 supplementing Directive 2010/31/EU of the European Parliament and of the Council. Official Journal of the European Union, 19 April 2012.

Hamdy, M., A. Hasan, and K. Siren. 2013. "A multi-stage optimization method for cost-optimal and nearly-zero-energy building solutions in line with the EPBD-recast 2010". *Energy and Buildings* 56:189-203. doi: 10.1016/j.enbuild.2012.08.023.

Italian Government. 2005. Legislative Decree 19 August 2005, no. 192 (and subsequent modifications and additions), complying the European Directive 2002/91/EC on the energy performance of buildings.

Italian Ministry of Economic Development. 2013. "Applicazione della metodologia di calcolo dei livelli ottimali in funzione dei costi per i requisiti minimi di prestazione energetica (Direttiva 2010/31/UE Art. 5)". Accessed December 2014. http://ec.europa.eu/energy/efficiency/buildings/doc/2013_it_cost-optimal_en.zip

Italian Organisation for Stardardisation (UNI). 2010-2014. UNI/TS 11300 (series). Energy performance of buildings.

Margiotta, Francesca. 2010. *Metodologia per la determinazione delle caratteristiche strutturali ed impiantistiche di "Edifici Tipo" del Parco Edilizio Nazionale ad uso ufficio e Valutazione del Potenziale di Risparmio energetico sulla base della fattibilità degli interventi di riqualificazione Energetica*. ENEA RdS/2010/197.