Energy Refurbishment of Social Housing Stock in Italy: Analysis of Some Scenarios from the Impact of Climate Change to Occupant Behaviour

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Abstract

In the period from the '40s to the late '70s, Italy implemented an extensive public social housing plan (INA-CASA and GESCAL) that is widely representative of the national residential building stock. Obviously, its energy performance is extremely poor and its refurbishment plays a key role in the national targets of GHG emissions reduction.

For these reasons, through historical research and survey of 145 social housing buildings, a building typology matrix with six-reference buildings has been developed following the IEE TABULA project method. Some typical refurbishment measures have been analysed, in term of global costs and total primary energy demand, considering different economics and climate change scenarios. The research has been carried out for Tuscany, central Italy, using both weather data sets for inland (Florence) and seaside (San Vincenzo). The input assumptions consider a constant thermal comfort level, in order to identify the measures that can provide comfort conditions to the occupants with the lowest value of energy demand. The results of this study, taking into account the impact of global warming on the Mediterranean climate, the high thermal inertia of typical buildings, and different user's behaviours, show that the combination of measures with advanced and standard performance level can be considered optimal in terms of global costs reduction.

1. Introduction

The European Directive 2010/31/EU, which aims to reduce energy consumption and the environmental impact of buildings, was implemented with the identification of a set of reference buildings, representative of the national stocks of the member states, through the TABULA research project followed by the EPISCOPE project (IWU, 2016).

In Italy, the TABULA research project (Corrado et al., 2014) defined the typological and technological characteristics of the reference buildings on the basis of the Piedmont Region building stock.

According to the common European methodology (European Commission, 2012) several combinations of energy efficiency measures have been applied to reference buildings in order to identify the optimal solutions under a cost-benefit profile. Finally, the results were used to issue the Italian decree 26/6/2015 on the minimum energy performance requirements for different types of intervention and the building energy rating system.

The most critical aspects of the application of the European methodology are:

- representativeness of the regional reference buildings compared to the national buildings stock;
- the energy performance calculation doesn't consider climate change, though the economic analysis is performed over the service life of the reference buildings;
- EN ISO 13790:2008 seasonal calculation methods (quasi-steady state) could fail in precisely evaluating the effects of high thermal inertia of the typical Italian residential buildings.

This research, starting from the European methodology framework (European Commission, 2012), has addressed these three aspects by taking into account a new set of reference buildings and climate change projections for Tuscany in central Italy.

2. Reference Buildings

Two major plans of social housing construction were activated in Italy, from 1949: INA-CASA (1949-1963) and GESCAL (1963-1973) that continued until the '80s (Acocella, 1980; Capomolla and Vittorini, 2003). INA-CASA buildings are characterized by very simple construction technologies and the most common types of buildings are the detached multifamily house and its combination in larger apartment blocks (INA-CASA, 1949).

From these premises, we selected a sample of 145 multi-family houses and apartment blocks, constructed in Pistoia (Beneforti and Ottanelli, 2012) between 1946 and 1977 under the INA-CASA and GESCAL plans.

This sample was analysed following the methodology developed for the TABULA and EPISCOPE projects that conform to the national housing census classification (ISTAT, 2011). By means of statistical analysis a strong correlation between A_e and V_G (R^2 = 0.93) and A_w and A_f (R^2 = 0.83) was observed and the dependence of space heating and cooling demands on these geometrical parameterswas analysed. Starting from the results at this preliminary stage (Pierangioli and Cellai, 2016), the Building Type Matrix shown in Table 1 was developed by arranging the sample into two historical periods characterized by different construction technologies (from 1946 to 1960 with 67 buildings, and from 1961 to 1977 with 78 buildings), and three building size classes based on V_G and the number of apartments (Pierangioli and Cellai, 2016).

Tables 2 and 3 show the Building Type Matrix envelope construction technologies and the HVAC system typologies.

The data derived from the TABULA project database (Corrado et al., 2014), local INA-CASA and GESCAL archives, and technical references (UNI, 2014-a).

Table 1 – Building Type Matrix (Pierangioli and Cellai, 2016)

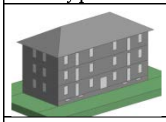
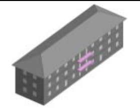
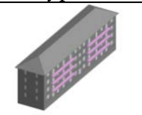
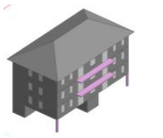
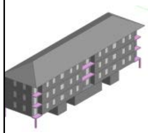
	DIMENSIONAL CLASS		
	(1) SMFH $V_G \le 2700$ nU≤8	(2) MMFH $2700<V_G<4800$ 8<nU≤15	(3) AB $V_G \ge 4800$ nU>15
(1) 1946 1960	Type 1.1  sample size: 26 buildings 6 apartments A_f=496.2 m² V_G=1987.0 m³ A_e/V_G=0.6 m⁻¹ A_w=79.1 m² A_w/A_f=0.16	Type 1.2  sample size: 28 buildings 12 apartments A_f =872.4 m² V_G=3428.2 m³ A_e/V_G=0.54 m⁻¹ A_w=129.6 m² A_w/A_f=0.15	Type 1.3  sample size: 13 buildings 24 apartments A_f =1618.8 m² V_G=6293.7 m³ A_e/V_G=0.47 m⁻¹ A_w=266.0 m² A_w/A_f=0.16
(2) 1961 1977	Type 2.1  sample size: 30 buildings 6 apartments A_f=485.7 m² V_G=1893.1 m³ A_e/V_G = 0.61 m⁻¹ A_w=89.7 m² A_w/A_f=0.18	Type 2.2  sample size: 26 buildings 12 apartments A_f =954.3 m² V_G=3697.5 m³ A_e/V_G=0.58 m⁻¹ A_w=176.4 m² A_w/A_f=0.18	Type 2.3  sample size: 20 buildings 16 apartments A_f =1633.2 m² V_G=6201.9 m³ A_e/V_G=0.50 m⁻¹ A_w=286.4 m² A_w/A_f=0.18
(1) Small Multi-Family House (2) Medium Multi-Family House (3) Apartment Block			

Table 2 – Thermal properties of building envelope components

	BLDG. TYPES 1.1, 1.2, 1.3	BLDG. TYPES 2.1, 2.2, 2.3
External walls	Load bearing brick and stone masonry no thermal insulation U=1.55 W/(m² K)	Multilayer masonry (hollow brick, air gap, hollow brick) no thermal insulation U=1.25 W/(m² K)
Semi-exp. walls	Load bearing brick masonry; U=1.80 W/(m² K)	Hollow brick masonry; U=1.60 W/(m² K)
Floors and ceilings	Reinforced brick concrete slab no insulation: - external floor: U=1.70 W/(m² K) - semi-exposed floor: U=1.40 W/(m² K) - semi-exposed ceiling: U=1.75 W/(m² K)	
Roof	Pitched roof with brick-concrete slab; U=2.00 W/(m² K)	
Basement	Concrete floor on soil; U=2.20 W/(m² K)	
Window glass	Double 3-6(air)-3 clear glazing; Wood frame; U_w= 3.1 W/(m² K); g = 0.76;	

Table 3 – HVAC system of reference buildings

	BLDG. TYPES 1.1, 1.2, 1.3	BLDG. TYPES 2.1, 2.2, 2.3
Heating	Traditional gas boiler (individual system); hot water radiators (70 °C/60 °C) with zone thermostat	
Cooling	Direct expansion multi-split system (individual system)	
Ventilation	Natural ventilation provided by window opening.	

3. Research Method

3.1 Climate Boundary Conditions

Previous studies (De Wilde and Coley, 2012) highlight the importance of evaluating the climate change impact in order to assess energy refurbishment strategies. For this reason, the climate boundary conditions used in this research incorporate possible results of global warming projections.

In particular, energy simulations were carried out with three different weather data sets. The first was assumed as representative of the current climate up to the year 2035. The other two represent the future climate change, as projected for the periods 2036–65 and 2066–95, within the worst-case Representative Concentration Pathways 8.5 scenario. The current weather data sets used in this study are Test Reference Years built by CTI (Italian Thermotechnical Committee) on the basis of data collected between 2000 and 2009 for the city of Florence, and by ItMeteoData on the basis of data collected between 1990 and 2009 for San Vincenzo. Both locations lie in the Hot Summer Mediterranean climate (Köppen climate classification Csa). The first was chosen to represent the Italian climatic zone D (inland sublittoral climate), the second, as an example of the more mild climatic zone C (coastal climate). The Florence climate, in particular, is interesting because it features one of the hottest summers and coldest winters among the big cities in the central and southern part of Italy. Moreover, HDD and CDD of the Florence weather station are used by ENEA to define the Super Index parameter for the performance evaluation of Italian energy end-use consumption in different economic sectors (ENEA, 2016). HDD and CDD of the current weather data sets are reported in Table 4.

Table 4 – Heating and cooling degree days for the study locations

Site	*HDD* (20 °C)	*CDD* (23 °C)
Firenze	2037	277
San Vincenzo	1831	118

The future weather data sets were processed by means of the "morphing" method (Belcher et al., 2005), adjusting the current weather on the basis of the results of high-resolution regional climate model COSMO CLM developed by the Euro-Mediterranean Centre on Climate Change. Future weather data present an annual average temperature higher than current one of 1.8 °C in the medium-term and of 4.3 °C on the long-term for Florence and, respectively, 2.1 °C and 4.5 °C for San Vincenzo.

3.2 Energy Efficiency Measures (EEMs)

The EEMs analysed were selected on the basis of the official data on the energy refurbishment measures that have been mostly applied under the tax benefit programs promoted by the Italian Government since 2006 (Nocera, 2015).

In order to carry out a preliminary analysis, EEMs were applied to Building Type 2.1 and 1.3. Every EEM is characterized by two levels of performance: one moderate level (level 1) which just complies with the Italian Decree 26/6/2015 (minimum energy performance requirements for buildings and building elements) and a second level with advanced energy performance (level 2).

Tables 5 and 6 report the performance parameters, the investment and maintenance costs, and the service life of the different EEMs. In order to take into account the interaction between different measures as, for example, the external envelope thermal insulation that allows the reduction of the boiler size, the selected EEMs were combined in 54 EEMs packages.

Table 5 – EEM on building elements

	LEVEL 1	LEVEL 2
Name	ETI1	ETI2
Ext. walls	EPS insulation layer on the external side	
	<u>*Climatic zone C*</u> U = 0.40 W/(m^2 K) C_I =C_R: 75.5÷77.9 €/m^2 <u>*Climatic zone D*</u> U = 0.36 W/(m^2 K) C_I=C_R: 77.9 ÷80.4 €/m^2	U = 0.24 W/(m^2 K) C_I=C_R: 85.2÷87.7 €/m^2
Semi exposed ceiling	Glass wool insulation layer on the upper side	
	<u>*Climatic zone C*</u> U = 0.34 W/(m^2 K) C_I=C_R: 12.2 €/m^2 <u>*Climatic zone D*</u> U = 0.28 W/(m^2 K) C_I=C_R: 15.1 €/m^2	U = 0.20 W/(m^2 K) C_I=C_R: 17.2 €/m^2
Semi exposed and ext. floors	EPS insulation layer on the lower side	
	<u>*Climatic zone C*</u> U = 0.42 W/(m^2K) C_I=C_R: 65.0 €/m^2 <u>*Climatic zone D*</u> U = 0.36 W/(m^2K) C_I=C_R: 69.2 €/m^2	U = 0.24 W/(m^2 K) C_I=C_R: 75.6 €/m^2
Name	WDG(S)	WTG(S)
Windows	Double low e. clear glass with wooden frame <u>*Climatic zone C*</u> U_w= 2.35 W/(m^2 K) C_I=C_R: 440 €/m^2 <u>*Climatic zone D*</u> U_w= 2.10 W/(m^2 K) C_I=C_R: 520 €/m^2	Triple low em. Glass with PVC frame; U_w = 1.1 W/(m^2 K) C_I= C_R: 625 €/m^2
Shading	External venetian blind activated from May to September when global solar irradiation on windows exceeds 300 W/m^2 (UNI, 2014-b); CI=CR: 105 €/m^2	
Service life of external thermal insulation: 30 years (40 years for ceiling insulation) Service life of windows: 30 years Service life of shading devices: 20 years		

The EEMs combinations include the possibility to leave the current building envelope or HVAC system un-refurbished.

Table 6 – EEM on heating generation system

	LEVEL 1	LEVEL 2
Name	CB	DX
Gen. system	Condensing gas boiler C_I= C_R: 2600 €/apt. CM: 39 €/year*apt. Service life: 20 years	Direct expansion multi-split system C_I = C_R: 5800 €/apt. CM: 232 €/year*apt. Service life: 15 years

3.3 Simulation and Cost Analysis Assumptions

The 54 EEMs packages were simulated by means of dynamic energy simulation software EnergyPlus v.8.0; in order to calculate annual energy carriers demand and total primary energy demand for heating and cooling (kWh/(m^2 y)) the following assumptions were adopted:

- heating and cooling systems are available 24 h/day and 7 days/week in order to keep operative temperature constant at 20 °C winter and 26 °C in summer;
- constant (00-24 from Monday to Sunday) natural ventilation rate equals to 0.3 h^{-1};
- simplified calculation of thermal bridges by the increase of the the U-value of the building elements according to technical standard EN ISO 13790:2008;
- internal heat gains from occupants, lighting and appliances are considered constant and equal to 3.0 W/m^2 (TABULA Project Team, 2013);
- window additional thermal resistance due to night closing of shutters and energy needed for hot water and lighting are not considered;
- the total primary energy demand is calculated by the official Italian conversion factors (2.42 for electricity and 1.05 for natural gas).

In order to identify cost-optimal energy refurbishment strategies, a global cost analysis was carried out for every EEM package, according to the general principles and methodology of the EU Regulation 244/2012 and accompanying guidelines (European Commission, 2012), and according to market-based data. The service life duration and the maintenance costs of building elements and HVAC components were gathered from UNI, 2008, and Di Giulio (1999). The electricity price includes taxes and ranges from 0.20 (preferential rate for heat pumps) to 0.29 €/kWh. The gas price includes taxes and varies from 0.75 €/Sm³ to 0.81 €/Sm³ depending on the yearly demand (AEEG, 2016). The following assumptions were adopted for the global cost calculation:

- costs related to refurbishment works, which have no influence on the energy performance or do not change between different EEM packages have been omitted;
- disposal costs have not been considered since, in long calculation periods, their influence is marginal due to discounting rate (EU Commission, 2012);
- n° 8 economic scenarios (Table 7) were analysed combining the following assumptions:
- two calculation periods (building service life): 50 and 80 years;
- two levels of real discount rate: 3 % and 5 % (EU Commission, 2012);
- two future trajectories of energy carrier prices: high increase projection (Capros et al., 2010) recommended by the European calculation methodology and updated moderate increase scenario (E3M-Lab, 2016).

Table 7 – Economic scenarios

Scenario	Service life	Energy price increase	Discount rate
1	50 years	moderate	5 %
2	50 years	moderate	3 %
3	50 years	high	5 %
4	50 years	high	3 %
5	80 years	moderate	5 %
6	80 years	moderate	3 %
7	80 years	high	5 %
8	80 years	high	3 %

4. Discussion and Result Analysis

The global cost and the energy performance of the different EEMs packages is shown for:

- Building Type 1.3 with economic scenario 1, which is the most favourable to moderate performance – low initial cost measures (Fig. 1a);
- Building Type 2.1 with economic scenario 8, which is the most favourable to high performance – high initial cost measures (Fig. 1b).

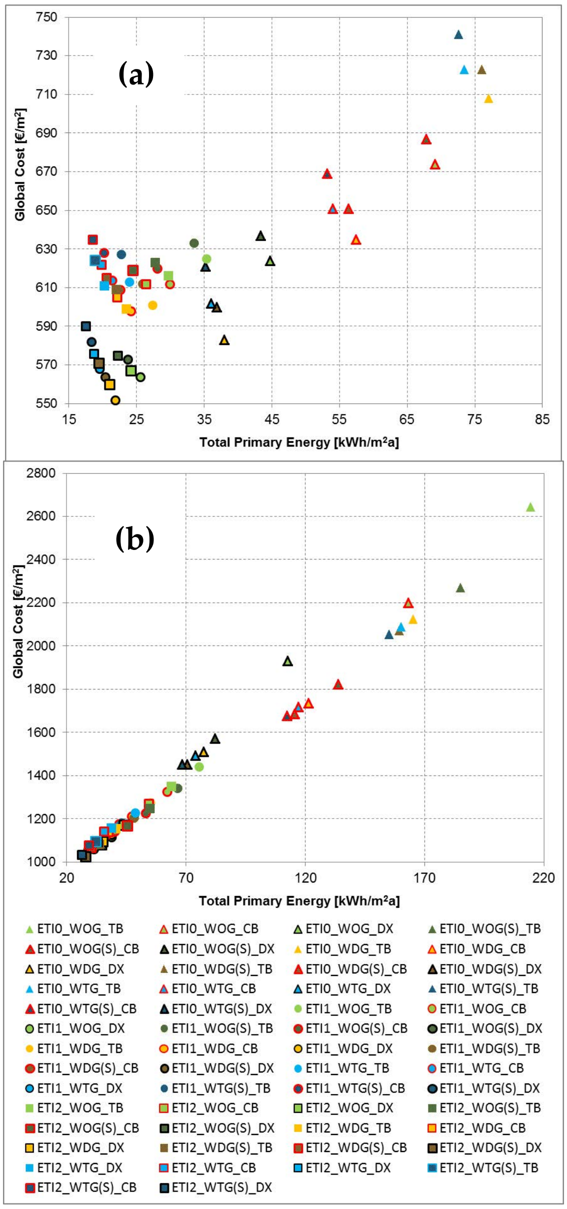


Fig. 1 – (a) building type 1.3 - C_G / EP plots West/East oriented, climatic zone C; (b) building type 2.1, South/North oriented, climatic zone D

Due to mild climate (zone C), South orientation, low V_G/A_e (0.47) and A_w/A_f (0.16) ratios the non-refurbished Building Type 1.3 presents a reduced primary energy need and therefore less sensitivity to redevelopment actions.

The results, shown in Fig. 1a, clearly show that, starting from not very high energy need and considering short-term economic scenarios, the solutions with the best energy performance do not coincide with the cost-optimal ones; the linear correlation between energy performance and global cost of different EEMs packages is very low. In this case, the cost-optimal solution features a standard level of external thermal insulation, standard windows (double low emissivity glazing), and a direct expansion multi-split system heat pump (ETI1_WDG_DX) with a C_G = 552.3 €/m² and EP_H+EP_C = 21.9 kWh/m².

On the contrary, Building Type 2.1 is more energy-intensive, due to higher V_G/A_e (0.61) and A_w/A_f (0.18) ratios, colder climate (zone D) and unfavourable orientation (high-summer, low-winter solar gains). Consequently, it has a more pronounced sensitivity to energy efficiency interventions. In this case the solutions with the best energy performances are also the cost-optimal ones, and there is a strong linear correlation between energy performance and the global cost of EEMs packages. The cost-optimal solution has an advanced level of external thermal insulation, standard windows with solar shading, and a direct expansion multi-split system heat pump (ETI2_WDG(S)_DX) with C_G = 1027.3 €/m² and EP_H+EP_C= 27.8 kWh/m².

For each building-type, climatic zone and facade orientation, 24 simulations (8 economic scenarios times 3 climatic scenarios) were performed and the resulting C_G/EP plots were processed in order to identify the most robust energy refurbishment solutions. These solutions present the lowest global cost output with the highest frequency on varying economic and climatic scenarios. The results are summarized in Table 8.

From the analysis of the results, it can be seen that:

- None of the analyzed EEMs, if applied alone, represents a cost-optimal solution. Thus, cost-effective energy refurbishment implies a combination of different EEMs, featuring the proper level of performance;
- Advanced level of thermal insulation (current Italian National requirements DM 26/6/2015) is a cost-optimal solution in any case except for the building with low V_G/A_e ratio (building type 1.3), located in the mild climatic zone C where the standard level implies a lower global cost. When this type of building is located in the climatic zone D, the standard level of external thermal insulation, even if not the cost-optimal solution, yields a global cost that lies within the range of 10 €/m² from the optimal solution.
- Double low emissivity glazing, compliant with current national requirements, represents the cost-optimal solution in most cases, while triple glazing could be considered a cost/benefit solution only when considering building-type 1.3, West/East oriented located in climatic zone D.
- The economic feasibility of shading devices is determined primarily by the orientation of the building. For West/East orientation solar shading devices are always a cost-optimal intervention due to the greater amount of solar gains received from the facades during the summer.

Table 8 – Most robust solutions and frequency of EEMs package

Building-type, climatic zone, orientation	EEMs package	Freq. (%)
Type 1.3, zone C, or. S/N	ETI1_WDG_DX	100
Type 1.3, zone C, or. W/E	ETI1_WDG(S)_DX	100
Type 2.1, zone C, or. S/N	ETI2_WDG_DX	50
	ETI2_WDG(S)_DX	50
Type 2.1, zone C, or. W/E	ETI2_WDG(S)_DX	100
Type 1.3, zone D, or. S/N	ETI2_WDG_DX	69
	ETI2_WTG_DX	31
Type 1.3, zone D, or. W/E	ETI2_WTG(S)_DX	69
	ETI2_WDG(S)_DX	31
Type 2.1, zone D, or. S/N	ETI2_WDG_DX	100
Type 2.1, zone D, or. W/E	ETI2_WDG(S)_DX	100

- In case of a higher A_w/A_f ratio and mild climate shading devices are cost-optimal even for the South/North orientation, just in case of low discount rate (3 %) scenarios;
- The direct expansion multi-split heat pump is by far the cost-optimal solution for the HVAC system, regardless of building-type, orientation and climatic zone;
- The economic factor that most influences the global cost results is the discount rate followed by service life;

- Climate change effect on global cost results is moderate, while a more relevant influence can be observed looking at the energy performance: in un-refurbished buildings, climate change causes a decrease in primary energy demand for heating that rather exceeds the increase of cooling demand, resulting in a total annual primary energy demand decrease, both on a medium and long-term scale. The opposite happens to energy refurbished buildings since the most robust EEMs combinations, listed on Table 8, worsen their medium and long-term energy performance; this happens because cost-optimal measures are more effective in reducing heating demand than cooling demand, with the latter growing much more than the former in future scenarios. These findings well match the conclusion of previous studies by the authors (Pierangioli et al., 2017).

Finally a simplified evaluation of the reliability of these findings in consideration of the more realistic user's behavior was performed. User presence and the related internal gains were derived from UNI/TS 11300-1 tailored rating profile (UNI, 2014 b). It was assumed that window opening for natural ventilation and solar shading devices operations match this profile as well. By the way of example, for building type 2.1, located in the climatic zone D, South/North oriented, a more realistic user profile implies an increase of primary energy demand and global cost of EEM's. This happens mainly because of the cooling demand rise due to the less efficient use of solar shading devices that are not operated during the central hours of weekdays. Moreover, increased cooling demand is not effectively balanced by a natural ventilation increase. Cost-optimal solution identification and ranking is affected as well, especially regarding windows selection: the economic feasibility for solar shading devices obviously weakens in favour of low g-value glazing.

5. Conclusion

This research investigated global costs and primary energy demand of common energy refurbishment measures applied to a couple of building models, representative of the Italian social housing stock build from 1946 to 1977 in Central Italy. Different climatic and economic scenarios have been considered. Although the results cannot be used to provide general and conclusive solutions, they are useful to highlight the trend of the effectiveness of climate change adaptation measures in Mediterranean climate.

The coupled energy-economic analysis shows that the selection of the cost-optimal refurbishment solution is significantly affected by the typological characteristics of the building, its orientation and climatic zone, in addition to the discount rate value which represents the most influential factor among the analysed economic parameters. These findings result in the necessity of an accurate preliminary assessment of the different refurbishment strategies in order to avoid non-optimal solutions.

In summary, the preliminary results of this research indicate that for most typological, economic, and climatic scenarios, cost-optimal solutions feature:

- advanced levels of external thermal insulation (beyond current national requirements);
- standard glazing system (double low emissivity) that complies with the current national requirements;
- operable solar shading devices in case of West/East orientation;
- a reversible direct expansion multi-split heat pump featuring a standard system efficiency that is already required by the Italian regulations.

Nomenclature

Symbols

A_f	Useful floor area of conditioned space (m^2)
A_e	Surface area of gross cond. volume (m^2)
V_G	Gross conditioned volume (m^3)
A_w	Window area (m^2)
U	Thermal transmittance ($W/(m^2 K)$)
U_w	Window thermal transmittance ($W/(m^2K)$)
g	Solar factor (-)
EP_H	Heating Primary Energy/A_f (kWh/m^2)
EP_C	Cooling primary energy/A_f (kWh/m^2)
C_G	Global Cost (€/m^2)
C_I	Initial investment costs (€/m^2)

C_R	Replacement costs (€/m²)
C_M	Maintenance costs (€/m²)
HDD	Heating degree days (Kd)
CDD	Cooling degree days (Kd)
ETI0	Current level of ext. thermal insulation
ETI1	Standard level of ext. thermal insulation
ETI2	Advanced level of ext. thermal insulation
WOG	Current double glazing
WDG	Double low emissivity glazing
WTG	Triple low emissivity glazing
(S)	Windows with shading system
TB	Traditional boiler
CB	Condensing boiler
DX	Direct expansion multi-split system

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