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nZEB design: challenging between energy and economic targets

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Abstract

Currently nZEB design represents a negotiation between energy targets and economic concerns. Whereby, it is indispensable that, staring from very preliminary phase of the project, a synergy between the building and system designers, the energy consultant and the economic valuer is set up.
Cost-optimal methodology together with statistical analyses developed with Minitab software was applied to analyze a new high performing single-family house, in Northern Italy, in order to define how energy and economic aspects could influence the preliminary design phase of the project.

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Keywords: nZEB; cost-optimal level; energy design; cost optimization; Minitab investigation

1. Introduction and methodology

Finding cost-optimal solutions towards nearly zero energy buildings in accordance with Energy Performance Building Directive (EPBD) recast is a great challenge. Indeed, in order to reach the 20-20-20 targets the EU energy policy introduced new ambition levels related to the spread on a large scale of nZEB and linked the nZEB concept with the cost-optimal level one, which is defined as the energy performance level which leads to the lowest cost during the estimated economic lifecycle of the building. Cost levels thus can be seen as a first step towards the achievement of the nZEB targets and EPBD recast attempted to go one strong step forward economic evaluations in building design. Consequently, building design represents a negotiation between energy targets and economic concerns. Nowadays it is indispensable that, starting from very preliminary phase of the architectural project, a

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synergy between the work of the building and system designer, the energy consultant and the economic valuer is set up.

The aim of this research is to analyze how energy and economic aspects could influence the preliminary design phase of the project and the choice in building energy strategy. In detail, this study focused on the definition of cost-optimal and nZEB scenarios for a new single-family house, in North Italy, that could constitute a significant example of real reference building [1], representative of Italian residential dwellings. In particular, in Italy single family houses represent the second most diffuse building typology across the national area, as reported into the national buildings stock census.

The comparative methodology framework of the EBPD, the so-called cost-optimal analysis, was followed and 16 different energy scenarios were defined without producing any change in the architectural appearance of the building. Scenarios energy assessment was performed with the quasi-steady-state method according to the European Standard EN 13790:2008 [2]. The costs of the different energy configurations were estimated through the application of global cost method according to the European Standard EN 15459:2007 [3], for the purpose of establishing which of them has the lowest global cost and, consequently, represents the cost-optimal level. In order to test the stability of the obtained results, different sensitivity analyses were carried out by varying some input data that have a notable influence on the results. Furthermore, due to the complexity of the cost-optimal methodology and the high time required for carrying on the economic analyses, another statistic tool, Minitab, was exploited in order to find an alternative more simple and immediate optimization tool. In detail, some statistical analyses of the cost-optimal level for the considered scenarios were developed. These analyses are useful to highlight the role played by some parameters, such as residual value, that are fundamental for the real estate market but that are not explicit in global cost graph.

2. Architectural design

The case study consists of a two-storey single family house with a net conditioned floor area of about 180 m² and characterized by a net floor height of 2.7 m and a conditioned net volume of 550 m³. The building, whose main axis is Est-West oriented, on three sides is isolated and neighbouring with another rural building on the west side. Rooms are located to maximise indoor comfort during use; living areas facing south, and service areas to the north. The southern façade is mostly glazing while the northern one presents little windows; the window-to-wall ratio is equal to 30%. Windows are equipped with exterior horizontal overhangs on the South façade designing in order to prevent summer overheating and allow useful solar gains in winter. The structure is built in reinforced concrete with insulated external walls in concrete block covered by a plaster layer. The roof is insulated as the ground floor slab in contact with the ground. Windows are constituted by a low-e double glass filled with air and by an aluminium frame with thermal break.

Since the building is located in Piedmont Region, Northern Italy (climatic zone E), the envelope U-values are set in compliance with the minimum values required by national regulation for the subsidised level [4]; this minimum level of thermal insulation is indicated with the number 1 in the following graphs.

Space heating is provided by a gas condensing boiler; heating terminals are radiant floors. Space cooling is supplied by a multi-split air conditioner with direct-expansion units. Domestic hot water (DHW) is provided by two flat plate solar collectors are installed on the roof, designed to cover 60% of the DHW net energy need, with auxiliary electric boiler. Moreover, in order to comply with national regulations [5] on the minimum total power output for photovoltaic system, 15 crystalline silicon panels (about 20 m²) are installed on the roof, with a total power of 2.6 kW_{peak}. This system configuration is indicated with the letter A.

3. Energy scenarios

In this research other three configurations with various energy performances were defined for both the building envelope and the HVAC system. From the combination of these different solutions for envelope and system, 15 energy design scenarios were investigated further reference building described in the previous paragraph (RB-1A).

Higher insulation levels of the envelope components were obtained by increasing the insulation thickness and by substituting double glasses with triple one. In scenarios associated to number 2, 3 and 4, U-values are, respectively, the optional values set by the Turin city regulation [6], passive house standard [7] and ClimateHouse A certification [8].

Alternative and more efficient system solutions together with controlled mechanical ventilation (VMC) and three options for the solar system were supposed. In detail, system scenario B consists in gas condensing boiler with radiant floors for space heating, multi-split air conditioner for space cooling, VMC, solar collectors covered 60% of DHW production, 20 photovoltaic panels (about 27 m²) with a total power of 3.4 kW_{peak}. System scenario C is constituted by water-to-water heat pump for space heating and cooling with radiant floors as terminal devices, solar collectors covered 60% of DHW production, 40 photovoltaic panels (about 55 m²) with a total power of 7 kW_{peak}. System scenario D is equal to scenario C with VMC in addiction.

Energy performances of different energy design scenarios were assessed with the quasi-steady-state method according to the European Standard EN 13790:2008 suitable for preliminary energy evaluation, and reported on the x-axis of the graph in Figure 1. The annual overall delivered primary energy includes energy use for heating, cooling, DHW production, lighting, equipment, ventilation and PV production taking in account on-site consumption and surplus electricity going to utility grid. Primary energy values were calculated using Italian primary energy factors (e.g. 1.09 for natural gas and 2.17 for electricity).

4. Economic analysis and global cost calculation

According to cost-optimal methodology, financial performances of different energy scenarios were valued with global cost calculation, which consists in the estimation of the net present value of costs incurring in a defined calculation period, considering residual value of components with longer life-span. More formally, the formula for the calculation of the global cost is given by equation (1):

$$C_G(\tau) = C_I + \sum_J \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) * R_d(i) \right) - V_{f,\tau}(j) \right] \quad (1)$$

where C_G (τ) represents the global cost referred to starting year τ_0, C_I is the initial investment cost, $C_{a,i}$ (j) is the annual cost for component j at the year i (including running costs and periodic or replacement costs), R_d (i) is the discount rate for year i, $V_{f,\tau}$ (j) is the final value of component j at the end of the calculation period (referred to the starting year τ_0). As shown in equation 1, the total global cost is determined by summing up the global costs of initial investment costs, periodic and replacement costs, annual costs and energy costs and subtracting the global cost of the final value.

A very important step for the application of the method consists in the evaluation of the investment cost of the building. Differently from the standard application of the cost-optimal methodology [9], where the initial investment cost is related only to the costs directly connected to the building energy systems, in the present study the investment cost was referred to the overall building construction cost. This choice was done in order to better estimate the total global cost and to find out the contribution of the cost related to the energy systems on the whole building cost. For the purpose of building cost estimation, two different estimation approaches were used in this study. In particular, the reference building was divided into two parts: a fixed part, which contains the structural elements and is equal for all the considered design scenarios, and a variable part, which contains only the elements that differ from scenario to scenario (e.g., windows, insulation layers, HVAC systems). With the aim of estimating the total construction cost for the case under examination, the fixed part was evaluated according to a synthetic (or parametric) approach, while the variable part followed an analytical estimation.

The synthetic construction cost estimation provides a preliminary evaluation of the building cost, that is affected by a high level of approximation but it is very useful to roughly measure the necessary resources for the works and it does not require very accurate and precise design data. The method is based on the possibility of defining a certain number of construction costs of similar building with reference to typological, technological, structural and distributive characteristics. These comparative buildings are taken into account when determining the construction cost of the building to be estimated. In this research, the comparable buildings were selected from the DEI cost manual [10]. It is necessary to mention that all the cost items related to the variables components of the building were parcelled out from the estimation value. The performed calculations led to reach a final value for the fixed part of the investment equal to 1138 €/m^2 of total conditioned floor area.

The variable part of the investment cost was valued through an analytical estimation in accordance with the price list of the Piedmont Region. In this case the estimate was based on a precise definition of the necessary quantities for the construction of the different considered scenarios and their unit price. In this sense, all the components affecting the energy performance of the building were computed and estimated one by one, sharpening the final results of the global cost calculation.

Another important step for the global cost calculation consists in the estimation of the running and maintenance costs. The running costs permit to evaluate the costs for energy consumption (electricity and natural gas) during the whole life cycle of the building. In the present application, the energy prices were referred to the actual values defined by the AEEG (Italian Authority for electricity and gas) [12]. The maintenance costs, including repair and servicing costs, were calculated as a percentage of the initial investment cost of every single building component.

5. Cost-optimal level and sensitivity analysis

In order to find the cost-optimal level, that is the energy performance level that leads to the lowest cost during the lifecycle of the building, it is necessary plot the results of the global cost with the primary energy consumption for each solution. The results are summarized in Figure 1, where the x-axis represents the primary energy consumption (kWh/m^2 per year) and the y-axis represents the global cost (€/m^2) considering a discount rate equal to 3%. As it is possible to see from Figure 1, the optimal solution is related to the scenario 2C, that corresponds to optional values of Turin city regulation for thermal insulation, water-to-water heat pump for space heating and cooling with radiant floors as terminal devices, solar collectors covered 60% of DHW production, photovoltaic system of 7 kW$_{peak}$.

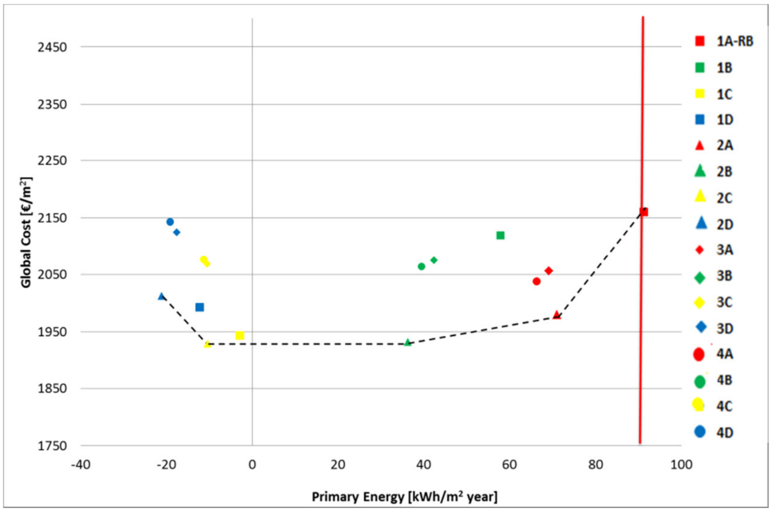

Fig. 1. Cost-optimal curve for the case under investigation.

As requested by the European Guidelines [11], in order to test the stability of the results obtained through the cost-optimal model, a sensitivity analysis was performed. Sensitivity analysis concerns a "what if" kind of questions to see in the final answer is stable when the input are changed. Sensitivity analysis is standard practice in ex-ante assessments when outcomes depend on assumptions on key parameters of which the future development can have a significant impact on the final result. For this study four types of sensitivity analysis were carried out: i) increase of the energy prices with an annual percentage rate of 2,8%; ii) reduction of the calculation period (20 and 10 years); iii) variation of the discount rate (5, 1 and 0,5%); iv) introduction of tax credits referred to the investment cost with an percentage rate of 65 and 36%. The results of the sensitivity analysis are summarized in Figure 2 (in graphs the black dotted-broken line refers to the first evaluation reported in Fig.1). As it is possible to see, the results of the initial model are confirmed and the 2C scenario still remains the best performing solution.

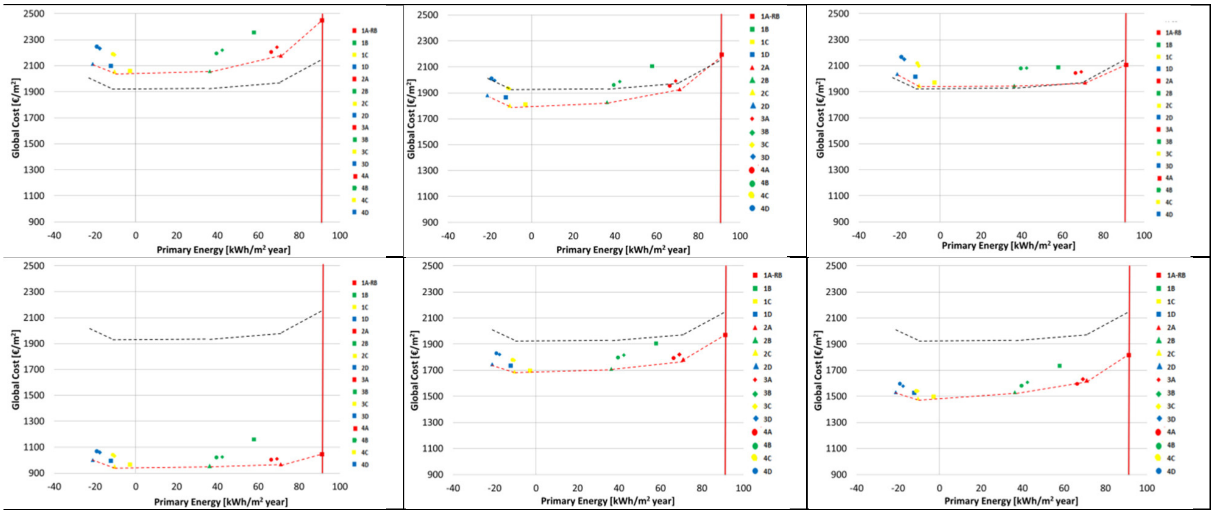

Fig. 2. Sensitivity analysis for the model (from top left, clockwise: increase in energy prices; decrease of discount rate; increase of discount rate; reduction of calculation period; introduction of tax credit for 65%; introduction of tax credit for 36%).

6. Minitab investigation

The final part of the research aimed at further exploring the cost-optimal level of the considered design scenarios by means of a stochastic approach based on the Minitab software. For the purpose of the Minitab application the 16 design scenarios have been considered has a 4 x 4 factorial plan, defined by the envelope and systems variables.

Firstly, the Minitab analysis proved the statistical significance on the two aforementioned variables for the cost-optimal model. In particular, the Anova Two Way statistical test was implemented in the case under investigation, which allowed to analyze the effects of investment costs related to envelope and systems on the global cost. From the Anova results, it is possible to affirm that both the variables used in the cost-optimal analysis have a statistical significance. Moreover, another statistical test, namely Fisher distribution, was applied and it allowed to state that the envelope variable is more important and influential than the system variable in the determination of the global cost.

Secondly, the Minitab tool was used for the analysis of the cost-optimal level for the considered scenarios and various investigations were performed in order to include in the evaluation different variables. In fact, it is possible to highlight that the cost optimal methodology allows to combine only the global cost and the energy consumption for the selection of the best performing solution, excluding from the analysis other important variables, such as the market value of the building. In this sense, it is of particular interest to analyze the role of the numerous parameters involved in the evaluation on the selection of optimal solution.

As an example, Figure 3 illustrates the results of the Minitab investigation considering as key variables the primary energy consumption (x-axis), the global cost (y-axis) and the residual value (z-axis). Considering residual value as third variable in the optimization analysis, the optimum is constituted by 2C configuration that also the cost-optimal model highlighted as the most suitable one. Indeed, 2C scenario has simultaneously the lowest energy consumption, the lowest global cost and the highest residual value.

To this end it is possible to affirm that the Minitab investigations are very sensitive to the different variables included in the investigation and further research should be devoted to better investigate the role of the different variable in the definition of the cost-optimal level.

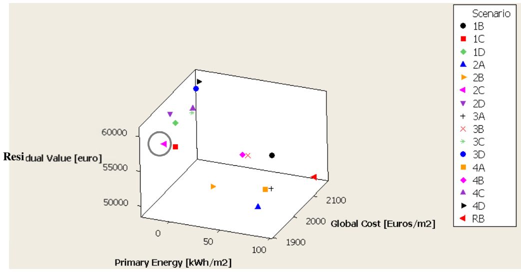

Fig. 3. Results of the Minitab investigation of the cost-optimal solution considering residual value; grey circle indicates the optimum solution.

7. Conclusions

In this study the cost-optimal methodology was used as a decision-making tool for supporting architects in energy planning of nearly-zero energy buildings during preliminary design phase. This methodology was used to evaluate the energy performance and financial concerns during the whole lifecycle of a single-family house for different design configurations; these included building envelope and HVAC systems. In particular, an innovative element in the application of this methodology consists in the evaluation of the overall building construction costs considering also their fixed part.

The optimal solution is related to the scenario 2C, that corresponds to optional values of Turin city regulation for thermal insulation, water-to-water heat pump for space heating and cooling with radiant floors as terminal devices, solar collectors covered 60% of DHW production, photovoltaic system of 7 kW_{peak}. Sensitivity analyses confirmed the result stability.

Finally, some statistical analyses of the cost-optimal level for the considered scenarios were developed employing Minitab software. The application of this optimization tool represents another original element of the research because currently it is scarcely used in energy and economic evaluations. These analyses are useful to point out some inherent weaknesses of cost-optimal methodology. Indeed, nowadays, it doesn't explicit in its results expressed in the global cost graph some parameters, such as market value of the building, that represent fundamental information on the real estate market.

To this end, it is possible to affirm that further studies are needed to experiment some multidimensional integrated models that are able to include in the evaluation different variables playing a crucial role in real estate market and not only energy and economic ones.

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