Designing a decision support system to evaluate the environmental and extra-economic performances of a Nearly Zero-Energy Building

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Abstract

Purpose – The cost-optimal analysis is not able to address the multi-dimensionality of the decision according to the new European objectives and International sustainable development goals in the field of the nearly-zero energy building (NZEB) design. The purpose of this paper is to study the role of multi-criteria decision analysis (MCDA) for guiding energy investment decisions.

Design/methodology/approach – The paper explores the Preference ranking organization method for enrichment of evaluations II (PROMETHEE II) application to support the project of transforming a rural building into a NZEB. The evaluation provides an estimate of the effects of alternative energy efficiency measures, involving energy consumption, life cycle costs, carbon emissions, property value and indoor comfort criteria. The study performs a multi-actors analysis in order to understand how different consumers' point of views can influence the final choice of the best investment. Furthermore, a multi-site analysis explores the spatial variation of NZEB building appreciation in the real estate market.

Findings – The PROMETHEE II-based model ranks 16 alternative solutions for the NZEB according to energy, economic and extra-economic criteria. The multi-actors analysis highlights the configuration of the NZEB building that best meets the needs of different end-users, respecting the European directives and national standards. The multi-site analysis concludes that location does not change users' appreciation and not influence the output for the best solution.

Originality/value – The MCDA occurs as a support tool that helps to optimize the preliminary design phase of NZEB through the exploration of the optimal solution considering crucial criteria in the energy and environmental and real estate market rules.

Keywords Multi-criteria decision analysis, Decision support systems, PROMETHEE method, Economic analysis, Energy systems, Co-benefit

Paper type Research paper

1. Introduction

In Europe, the building sector causes more than 40 per cent of the total energy consumption and 36 per cent of the CO_2 emissions (Blesl *et al.*, 2010; Klessmann *et al.*, 2011). Starting in 2009, the European Union (EU) issued several directives for the Member States in order to encourage the reduction of energy consumption, promoting the use of renewable energy sources (RESs). In this context, an integrated approach between energy policies and the match against climate change was foreseen with the 2020 Climate–Energy Package at the EU level. In line with the numerous Directives proposed by the EU, in 2015, more than 150 international leaders decided to contribute to global development, promote human well-being and protect the environment by approving the 2030 Agenda. The essential elements of this document are the 17 Sustainable Development Goals (SDGs) (Global Reporting Iniziative, 2015). They aim to create sustainable communities, fight climate change and build peaceful societies. In this context, buildings play a fundamental role, promoting solutions that aim to reduce environmental impacts, decrease the consumption of resources and create healthy places for citizens.

Following, the Member States committed themselves to a process aimed at fighting climate change by 2050 through the adoption of community and national decarbonization policies (European Commission, 2011). In particular, the recast of the Energy Performance Buildings Directive (EPBD) (European Commission, 2010), amending Directive 2002/91/EU (European Commission, 2002), has defined that all new buildings will be Nearly Zero-Energy Buildings (nZEB or NZEB) by the end of 2020; this represents a real step-change into the current way of designing and constructing, both from an architectural perspective and from the side of technical systems, including Heating, Ventilating and Air Conditioning (HVAC) systems and lighting appliances. Moreover, the EPBD recast proposes the cost-optimal methodology for addressing the energy project for the buildings. Generally speaking, the cost-optimal analysis is based on the evaluation of the best performing energy solution which leads to the lowest cost during the estimated economic lifecycle of the building (Kurnitski *et al.*, 2011).

Despite the utility of the cost-optimal analysis in addressing the design of energy retrofit projects, the applications of the method to real-world problems have pointed out some inherent weaknesses. In particular, a large part of the scientific literature in the domain of NZEB has focussed on design strategies and technological systems, while little research on the extra-economic analysis exists (Berry and Davidson, 2015). Moreover, the cost-optimal approach as proposed by the European Directive is not able to address the complexity of the decision problem because it does not make explicit in its results some parameters that represent essential information for the decision-makers such as the environmental impacts or the socio-economic effects of the retrofit solutions (Kang, 2015). On the economic side, there is no established model of evaluation capable of capturing the environmental and extra-economic impacts as demanded by the European Commission (European Commission, 2018, 2014). In recent years, flourishing literature research has been developed to classify non-energy benefits such as environmental, healthy, ecological and economic benefits that need to be included in the feasibility evaluation (Bisello and Vettorato, 2018; Ferreira *et al.*, 2017; Ürge-Vorsatz *et al.*, 2014). The incorporation of these externalities, called co-benefits or co-impacts, into decision-making frameworks could help to consider the full range of impacts generated by the energy investments and to obtain a general evaluation of the project considering all the actors involved in the project (Becchio *et al.*, 2018; Bottero and Bravi, 2014; Copiello and Bonifaci, 2015).

The paper addresses this gap by proposing a more comprehensive decision support system able to consider the different aspects involved in NZEB decision problems apart from energy consumptions and economic costs. In particular, in the light of the limitations mentioned above, the present study aims to expand the cost-optimal methodology and to investigate the role of multi-criteria decision analysis (MCDA) (Dell'Ovo *et al.*, 2017; Figueira *et al.*, 2005; Figueira and Roy, 2002; Yang *et al.*, 2018) for supporting real-world decision problems in the context of the production of NZEBs at the local level. Indeed, MCDA methods have become increasingly popular in decision-making in the energy field because of the multi-dimensionality of the problem and the complexity of the socio-economic and biophysical system (Wang *et al.*, 2009). This work shows how the MCDA model could become a useful tool to assist the formation of energy efficiency policy at the local level providing a rapid estimation of the overall performance of building considering the efficiency measures on building energy consumption, costs, carbon emission, real estate value and indoor comfort. The research will explore the use of the Preference ranking organization method for enrichment of evaluations II (PROMETHEE II) method for the definition of the cost-optimal and NZEB scenarios for a new single-family house, in Northern Italy, that could constitute a significant example of real reference building representative of Italian residential dwellings (Barthelmes *et al.*, 2016). Since in the real estate market the evaluation criteria are not as important for consumers, different user profiles have been defined (Bottero *et al.*, 2020b; Komolafe *et al.*, 2019). With the help of experts, five scenarios that capture different points of view have been investigated to verify how the ranking of the alternatives proposed for the case study varies. Furthermore, an exploration of the spatial variation of NZEB building appreciation in the real estate market has been hypothesized, proposing a multi-site analysis (Figure 1).

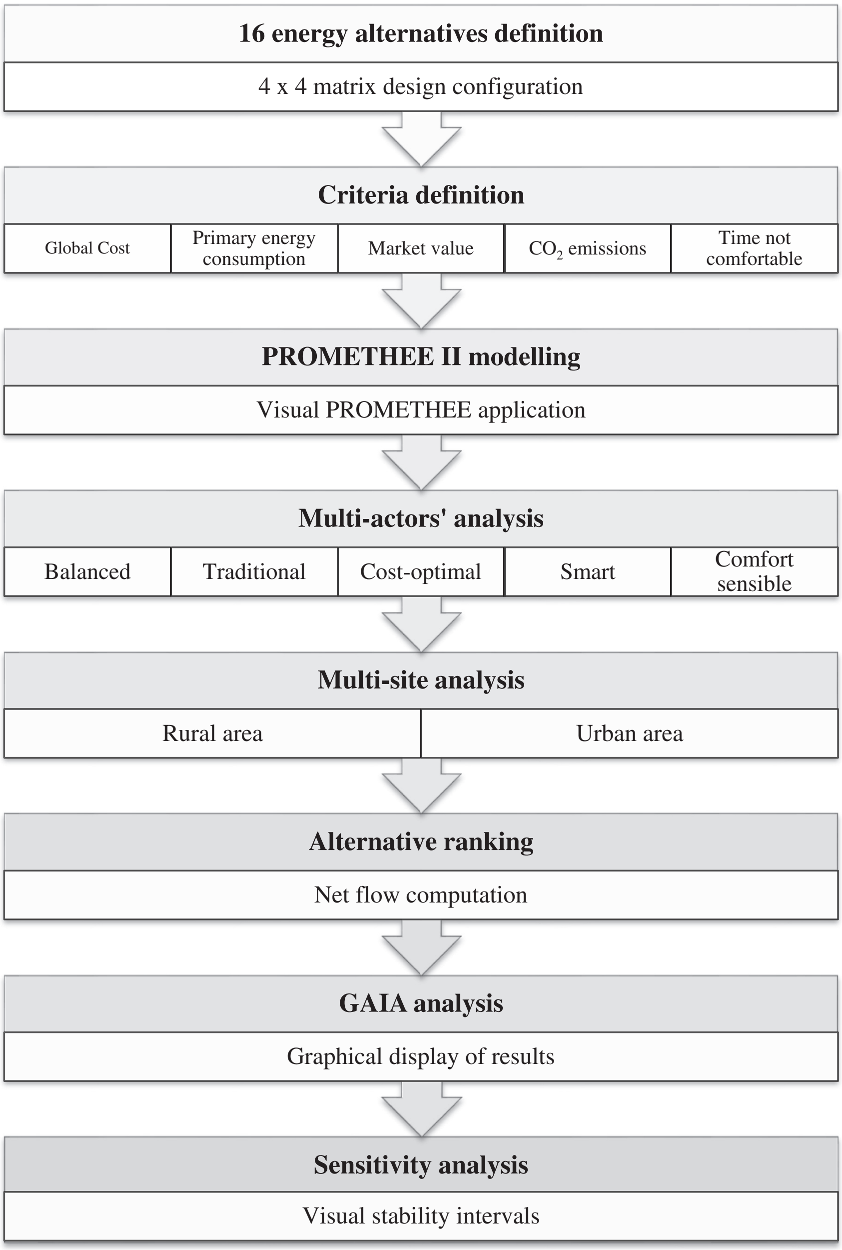


Figure 1.
Research flowchart

After the introduction, the paper is organised as follows: Section 2 illustrates the cost-optimal analysis for NZEB according to EBPD recast; Section 3 presents a literature review about MCDA method and PROMETHEE application in the energy sector; the methodological background of the PROMETHEE model follows in Section 4; the application of the MCDA model to an Italian real case study is shown in Section 5; Section 6 explains the multi-actor scenarios; Section 7 discusses the findings of the research and performs sensitivity analysis and, finally, Section 8 summarises the main conclusion of the work.

2. Cost-optimal analysis for NZEB

The European Directive 2010/31/EU imposed on the Member States, the implementation of a standard framework for an integrated methodology aimed at calculating the energy performance of buildings and optimal levels in terms of costs. The objective of the methodology is to identify the amount of energy needed to meet the energy demand, which leads to the lowest cost during the estimated economic lifecycle (Corgnati *et al.*, 2013; D'Alpaos and Bragolusi, 2018; Kurnitski *et al.*, 2011). Therefore, two types of information are considered: the energy performance, defined by primary energy consumptions and the economic performance, analysed through the global costs methodology (Arroyo *et al.*, 2016; Mendoza-Vizcaino *et al.*, 2016).

Based on the calculation of primary energy consumptions and global costs related to different energy efficiency solutions, the cost-optimal approach allows evaluating the effectiveness of alternatives energy efficiency measures/packages/variants, which represent the hypothesis of energy retrofit operations.

2.1 Determination of the primary energy consumption

According to the cost-optimal methodology, the term "energy performance of a building" refers to the calculated or measured amount of energy required to cover the energy needs including, amongst other things, the energy uses for heating, cooling, ventilation, domestic hot water and lighting.

Usually, the energy performance indicator EP_{gl} takes only into account two indicators, the EP_i referring to the requirements for heating and the EP_{dhw} related to the production of domestic hot water (DHW).

The calculation formula is shown in Eqn (1):

$$EP_{gl} = EP_i + EP_{\text{dhw}} \tag{1}$$

2.2 Calculation of global costs

The cost-optimal framework methodology is based on the net present value (global costs) methodology. This cost is calculated by respecting the European Standard EN 15459-2017 and considers the investments during the whole calculation period. The global cost is calculated with Eqn (2):

$$C_g(\tau) = C_I + \sum_j \left[\sum_{i=1}^{\tau} \left(C_{a,i}(j) \times R_d(i) \right) - V_{f,\tau}(j) \right] \tag{2}$$

where $C_g(\tau)$ is the global cost (referred to the starting year τ_0), C_I is the initial investment costs, $C_{a,i}(j)$ is the annual cost year i for component j (including running costs and periodic or replacement costs), $V_{f,t}(j)$ is the final value of component j at the end of calculation period (referred to the starting year τ_0) and $R_d(i)$ is the discount rate for year i.

3. MCDA and PROMETHEE application in energy planning: a literature review

MCDA methods represent a considerable part of the approach to support simultaneous evaluations of the project contribution taking into account both technical elements, which are based on realistic observations and non-technical elements, which are based on social visions (Bottero *et al.*, 2018b; Figueira *et al.*, 2005). MCDA provides useful support in complex decisions as the methods allow to make a comparative assessment of alternative projects or different measures (Lombardi and Ferretti, 2015). These methods permit several criteria to be taken into account simultaneously, and they are designed to help decision-makers to integrate different options, which reflect the opinions of the involved actors. Participation of the DMs in the process is a central part of the approach.

Different theories exist within the context of MCDA methods that can be described as follows:

(1) Utility function theory: the utility-based theory (American-inspired) includes methods synthesising different points of view in a single function which is subsequently optimised (also called performance aggregation-based approaches), and it was introduced during the 1970s by Keeney and Raiffa (1993);

(2) Outranking relation: the outranking relation theory (French-inspired) aims instead to build a relationship of superiority that represents by the decision-maker preferences given the information at his disposal. This method, also called preference aggregation-based approach, compares two options to verify whether "alternative *a* is at least as good as alternative *b*" (Bouyssou, 1990);

(3) Sets of decision rules: the decision rule theory originates from the artificial intelligence domain, and it allows deriving a preference model through the use of classification or comparison of decision examples (Greco *et al.*, 2001).

The increasing demand for multidimensional decision-making models in the energy sector has led energy planners to grow experimentation of evaluation models based on the MCDA (Diakoulaki *et al.*, 2005; Gijsbers and Lichtenberg, 2014). MCDA-based models in the energy context help planners in managing problems that traditional models do not solve. Different evaluation criteria come into play when planning and choosing the best alternative amongst a set. The typical questions posed in the decisional problems in the energy field refer to the identification of the best place to realize new energy conversion or transmission structures (location problems) (Rosso *et al.*, 2014), on which type of energy resource or conversion technology to use (alternative solutions or energy policies) (Neves *et al.*, 2009; Yilan *et al.*, 2020), how to combine different energy sources and technologies to meet present and future energy needs (combination of alternatives) (Becchio *et al.*, 2017a). Location problems refer to the MCDA evaluation approach often used for evaluating large-scale, national and international energy interventions. The choice of the optimal location of energy generation interventions is often supported by analyses that take into consideration not only the technical but also the economic, environmental and social aspects (Katal and Fazelpour, 2018; Vishnupriyan and Manoharan, 2018; Wu *et al.*, 2019). With particular reference to the energy domain, Kurka and Blackwood (2013) and Strantzali and Aravossis (2016) offer an in-depth review about MCDA to support energy planning at different levels, from building to urban scale comparing different generation alternatives (Becchio *et al.*, 2017a; Ghafghazi *et al.*, 2010; Ziemele *et al.*, 2014).

An in-depth analysis of the scientific literature revealed that several studies highlight the environmental issue importance applying MCDA for sustainable energy planning and evaluating the CO_2 emissions avoided (Cavallaro and Ciraolo, 2005; Tsoutsos *et al.*, 2009). Other criteria used in energy decision-making processes refer to technical (efficiency, primary energy ratio), to economic (net present value, payback period), to environmental (greenhouse gas [GHG] emissions, noise, land use) and social aspects (job creation, social benefit, social acceptability) (Wang *et al.*, 2009) (Table I). It has to be noticed that little attention has been given to the evaluation of small-scale interventions such as individual buildings.

For the present research, one of the most popular MCDA techniques belonging to the outranking methods family was used. The two most prominent outranking approaches, the ELimination Et Choix Traduisant la REalité (ELECTRE) family of methods, developed by Roy and associates at Laboratoire d'Analyse et Modelisation de Systemes pour l'Aide a la Decision (LAMSADE), University of Paris Dauphine and PROMETHEE, proposed by Brans from the Free University of Brussels (Strantzali and Aravossis, 2016). Unlike ELECTRE methods, PROMETHEE does not merely perform a comparison in pairs of alternatives in order to classify them according to a series of criteria, but it allows to define the preference and the level of difference between the alternatives when determining the classification order. Different versions of the PROMETHEE method exist. PROMETHEE I was developed for partial ranking of the alternatives, while PROMETHEE II for the complete ranking of the alternatives by Brans *et al.* (1986). Their mathematical properties and their openness played a crucial role in their success. Recent papers by Behzadian *et al.* (2010) and Troldborg *et al.* (2014) highlight that many applications of the PROMETHEE methods exist in the different fields, including environmental management, water management, business, chemistry, logistics, transportation, manufacturing, energy management and social. In the energy context, the PROMETHEE applications have been concentrated on selecting and evaluating energy generation or exploitation alternatives from the district to the national level, comparing alternatives with renewable sources (Diakoulaki and Karangelis, 2007; Ghafghazi *et al.*, 2010). Mention is not be made to the fact that no application exists in the context of building energy management, mainly linked to the NZEB target.

The main features of the PROMETHEE II have been used for the selection of the method to be used. Firstly, PROMETHEE II calculates criteria preferences for different actors involved in the process and create aggregation data to compare alternatives. Secondly, PROMETHEE is integrated by a user-friendly software with results visualisation tools; Visual PROMETHEE. The graphical representations allow us to represent specific input and output data that are quick to read and easy to understand by individual local authorities, according to our goal of creating specific tools for local energy policies. Moreover, Visual PROMETHEE, being open-source, is accessible to any user for free.

4. PROMETHEE methodological framework

PROMETHEE is an outranking method for a finite set of alternative actions to be ranked and selected amongst criteria, which are often conflicting (Roy, 1993).

The PROMETHEE II method has to be developed according to subsequent steps:

Step 1: To establish an impact matrix. The first step consists in establishing an impact matrix that is a double entry table that links the alternatives with the evaluation criteria.

Step 2: To apply the preference function $P(a, b)$. For each criterion, a preference function $P(a, b)$ is applied to decide how much the alternative a is preferred to the alternative b. The value of the preference function varies between 0 and 1. The value 1 means that there is a strict preference for an alternative over another alternative. The value 0 means that the DM is indifferent between the two alternatives. Six preferences function are available in the PROMETHEE II method, namely, usual criterion, quasi criterion (U-shape), criterion with linear preference (V-shape), level criterion, linear criterion and Gaussian criterion (Bottero *et al.*, 2019c; Brans and Mareschal, 1994; Brans *et al.*, 1986). The preference functions also include different type of threshold, namely, indifference, preference and Gaussian thresholds. Indifference threshold (notation q) is the most significant deviation between two alternatives, which is considered negligible by the decision-maker (DM); preference threshold (notation p) is the smallest deviation between two alternatives which is considered by the DM sufficient to

Criteria	Description	Scale	Indicator	Source
Technical				
Energy demand	Annual energy demand	Quantitative	kWh/m^2	Wang *et al.* (2009)
Energy savings	Annual energy saved	Quantitative	kWh/m^2	Wang *et al.* (2009)
Primary energy	Energy consumption in primary energy	Quantitative	kWh/m^2	Becchio *et al.* (2017a)
Technological maturity	Reliability of the technology	Qualitative	1–9	Tsoutsos *et al.* (2009)
Self-supply of energy	Ratio between energy produced by RES and energy consumed	Quantitative	%	Van Alphen *et al.* (2007)
Blackouts avoided	Failures avoided through the most reliable system	Quantitative	%	Papadopoulos and Karagiannidis (2008)
Energy efficiency	Energy supplied respect to the capacity of the system	Quantitative	W/m^2K	Chatzimouratidis and Pilavachi (2009)
Service life	System expected life	Quantitative	years	Wang *et al.* (2009)
Environmental				
GHG emissions, PM emissions, CO2 emissions, Equivalent CO2 emissions	Polluting gas emissions related to heating, domestic hot water production, electrical uses	Quantitative	t/m^2	Becchio *et al.* (2017a); Kontu *et al.* (2015); Streimikiene *et al.* (2012)
Ecological footprint	Biological area necessary for the production of consumed resources	Quantitative	ha	Assumma *et al.* (2019); Chatzimouratidis and Pilavachi (2008); Ghafghazi *et al.* (2010)
Economic				
Investment costs	Initial costs	Quantitative	€/m^2	Grujić *et al.* (2014); Kontu *et al.* (2015)
Maintenance costs	Annual expenses to guarantee the efficiency of the system	Quantitative	€/m^2y	Marinakis *et al.* (2017)
Operational costs	Annual expenses related to the system function	Quantitative	€/m^2y	Cavallaro and Ciraolo (2005
Global cost	Total cost calculate in cost-optimal perspective	Quantitative	€/m^2	Becchio *et al.* (2017a)
Bills reduction	Annual economic savings	Quantitative	€/m^2y	Marinakis *et al.* (2017)
Internal rate of return	Internal rate of return	Quantitative	%	Papadopoulos and Karagiannidis (2008); Wang *et al.* (2008)
Net present value	Net present value	Quantitative	€	Sung Chul and Min (2004); van Alphen *et al.* (2007)
Total revenues	Annual revenues from self-produced electricity sale	Quantitative	€/y	Becchio *et al.* (2017a)
Payback period	Years needed to cover initial costs	Quantitative	years	Doukas *et al.* (2007); Wang *et al.* (2008)
Incentives	Part of the subsidised investment costs	Quantitative	€/m^2	Bottero *et al.* (2019c); Tsoutsos *et al.* (2009)
Asset value	Increase in real estate value	Quantitative	€/m^2	Becchio *et al.* (2017a); Dell'Anna *et al.* (2019a)

(*continued*)

Table I.
Main evaluation criteria for energy investments as resulting from the scientific literature

Criteria	Description	Scale	Indicator	Source
Social				
Green jobs	New green jobs created	Quantitative	No	Becchio *et al.* (2017a)
External costs	Public health cost	Quantitative	€/y	Chatzimouratidis and Pilavachi (2009, 2008)
Social acceptability	Public preference for energy infrastructure	Qualitative	1–5	Cavallaro and Ciraolo (2005); Lipošćak *et al.* (2006)
Visual impact	Visual disturbance of energy infrastructures	Qualitative	1–5	Georgopoulou *et al.* (1997)

Table I.

generate a full preference; Gaussian threshold (notation s) corresponds to the inflexion point of the Gaussian curve (Table II).

Step 3: To calculate the overall preference index $\Pi(a, b)$. The overall preference index $\Pi(a, b)$ represents the intensity of preference of a over b, and it can be calculated according to Eqn (3):

$$\Pi(a,\ b) = \sum_{j=1}^{k} w_j P_j(a,\ b) \tag{3}$$

where

$\Pi(a,\ b)$ is the preference degree of a over b, w_j is the weight of the criterion j, k represents the number of criteria, and $P_j(a, b)$ is the preference function of a over b with reference to criterion j.

Step 4: To calculate the outranking flows: the leaving flow $\Phi^+(a)$ and the entering flow $\Phi^-(a)$. In PROMETHEE II method for each alternative a there is a leaving flow (outranking) $\Phi^+(a)$ calculated by Eqn (4):

$$\Phi^+(a) = \frac{1}{(n-1)} \sum_b \Pi(a,\ b) \tag{4}$$

and a the entering flow (being outranked) $\Phi^-(a)$ calculated by Eqn (5):

$$\Phi^-(a) = \frac{1}{(n-1)} \sum_b \Pi(b,\ a) \tag{5}$$

Step 5: To compare the outranking flows and to define the complete ranking of the alternatives, PROMETHEE provides a complete ranking of the alternatives by determining the net flow, Eqn (6):

$$\Phi(a) = \Phi^+(a) - \Phi^-(a) \tag{6}$$

As mentioned above, Visual PROMETHEE graphically delivers results' representation. Geometrical Analysis for Interactive Aid (GAIA) is one of the visualisation methods available. Based on the PROMETHEE II method, GAIA provides a visual guide for the principal criteria that are used for ranking of the alternatives. GAIA matrix is constructed from a decomposition of the net outranking flows. The matrix data is then processed by a principal component analysis (PCA) algorithm and displayed on GAIA biplot. This transformation of a multi-criteria problem to a two-dimensional space and geometrical representation of relations between alternatives and criteria provides a new perspective to the problem with the inevitable loss of some relation characteristics (Vego *et al.*, 2008).

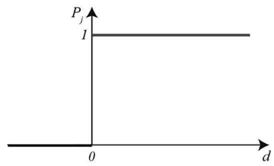
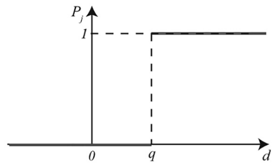
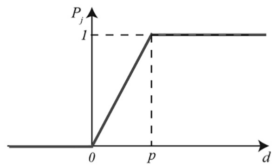
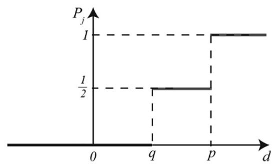
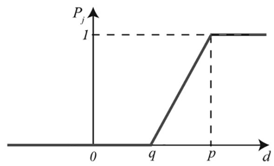
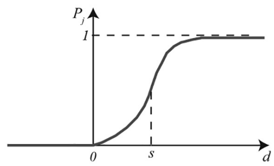
Preference function	Shape
Usual criterion	
Quasi criterion (*U*-shape)	
Criterion with linear preference (*V*-shape)	
Level criterion	
Linear criterion	
Gaussian criterion	

Table II.
Preference functions

5. Application

5.1 Description of the case study

The case study examined is the CorTau House, a real example of NZEB in Piedmont, located in Livorno Ferraris (North of Italy) (Plate 1). This building represents a real example of quality and high-energy performance, according to the NZEB requirements (Barthelmes *et al.*, 2016). This single-family residential building has been an architectural and energy experiment aimed at obtaining a replicable zero energy home in the Mediterranean climate, in which the architectural quality has been perfectly combined with high-performance system solutions (Barthelmes *et al.*, 2015a, b).

The case study consists of a single-family house with a net-conditioned floor area of about 180 m^2 and a conditioned net volume of 550 m^3 (Barthelmes *et al.*, 2015a). The building, whose central axis is East–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 per cent.

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 months The structure is constructed of reinforced concrete with insulated external walls of concrete blocks. The roof is insulated like the ground floor slab. The windows consist of a double low-emission glass filled with air and an aluminium frame with thermal break.

5.2 Energy systems alternatives

In this study, four different design configurations have been selected for both the building envelope and the HVAC system. The main goal is to create various design scenarios, which can be evaluated by their energy and economic performances.

Indeed, the European Directive EBPD recast recommends evaluating at least 10 different design scenarios to make sure that enough design options are evaluated and the choice of one of this is all-conscious. In this study, a 4×4 matrix based on the combination of four envelope design levels with four HVAC system configurations is proposed (Figure 2) (Barthelmes *et al.*, 2016).

The four-building envelope design configurations chosen refer to different energy performance requirement levels. Reference for the first level is made by the Italian directive for Climatic Zone E (where Livorno Ferraris is located); the second level refers to the voluntary value set by Turin's regulations (*Allegato Energetico di Torino*); the third one refers to the requirements necessary to obtain the Passivhaus certification. The last one refers to CasaClimaGold constraints. Different building envelopes were designed to satisfy these requirements and respect the thermal transmittances set. They are characterised by four different thermal insulation degrees, varying the thickness of the insulation layer and the walls and windows thermal transmittance.

Moreover, four different HVAC system configurations were defined (Table III). High-energy efficiency levels characterized these systems in order to reach the NZEB target. The selected HVAC systems are the condensing boiler (nominal efficiency fixed equal to 0.95) and the heat pump (coefficient of performance for the heating period set equal to 4.75 and energy efficiency ratio for the cooling period to 5.65). They are combined with natural or controlled mechanical ventilation (CMV). All configurations use the radiant floor panels as the emission system for heating, while different systems were set for cooling (radiant panels or split).

To reach the NZEB target, it is necessary to supply energy from renewable sources largely. Afterwards, in this study, solar thermal (ST) panels were considered in order to cover 60 per cent of the DHW supply, combined with a photovoltaic (PV) system if necessary. The peak values of the PV panels refer to Italian Directive in Systems 1 (2.6 kWp) and 2 (3.4 kWp),

Plate 1.
The rural building to be retrofitted (on the left); the current architectural design (on the right) (Barthelmes *et al.*, 2015a)

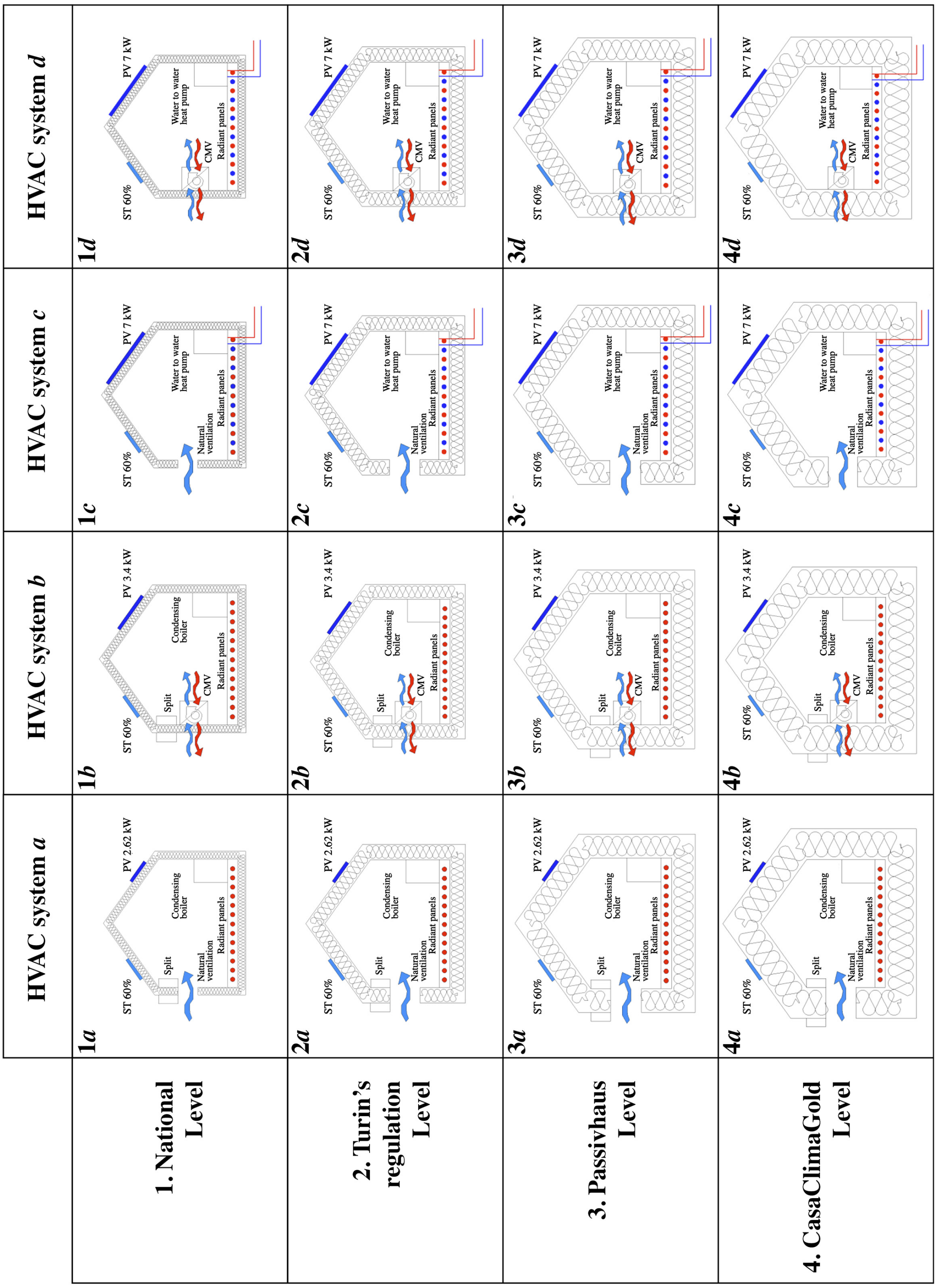


Figure 2.
Matrix of the 16 energy design alternatives (Barthelmes *et al.*, 2014)

while the peak value of 7 kWp in Systems 3 and 4 was defined in order to have a surplus of electricity production. From an energy point of view, it is interesting to understand how the combination of different sizes results in an optimal choice for an NZEB building. Based on this assumption, 16 energy alternative solutions have been designed, combining the eight initial configurations. In Figure 2, the building envelope configurations are identified with a number (1, 2, 3 or 4) while the different HVAC systems configurations with a letter (*a*, *b*, *c* or *d*).

6. Identification of the evaluation criteria and definition of the preference functions

The first step for the application of the PROMETHEE method consists in defining the evaluation criteria, which provide a measure of the impacts for the considered alternatives. In particular, the criteria derived from the legislative framework in the energy context of the European Standard Regulations. Moreover, the criteria also reflect the scientific literature in the context of energy projects and building physics (Al Garni *et al.*, 2016; Buso *et al.*, 2017; Munda, 2016).

6.1 Global cost

The global cost and the primary energy consumption are the criteria that are considered in the standard cost-optimal analysis (Barthelmes *et al.*, 2016). As mentioned in Section 2.2, the global cost was calculated according to the European Standard EN 15459-2017, which allows considering the total costs during the whole life cycle of the building. For the European Member States, the calculation period for residential and public buildings is determined by the Regulation No 244/2012 and amounts to 30 years.

The investment costs have been calculated with two different kinds of estimation typologies. The building was split into two parts; the first part is the "structure", equal for every package, evaluated through a synthetic estimation; the second one contains all the elements that differ from package to package (windows, insulation, concrete blocks) was made by an analytic estimation (Dell'Anna *et al.*, 2019b). The reference for this second cost share was made by the Piedmont region price list, where all building components are computed and estimated one by one (Piedmont Region, 2019).

The running costs allow evaluating the costs for energy consumption (electricity and natural gas) during the building's life cycle. The energy prices refer to the Italian Regulatory Authority for Energy, Networks and Environment (ARERA). The maintenance costs, including repair and servicing costs, are calculated in per cent of the initial investment cost of every building component, according to EN 15459-2017. As soon as every single incidence cost was provided. The global cost calculation can be assessed for every design package. According to EN 15459-2017, it is necessary to outline the general assumptions made for the financial data, as the calculation period is equal to 30 years and a discount rate equals to 3 per cent.

Table III. Design configuration for heating ventilation and air conditioning (HVAC) systems

HVAC system *a*	HVAC system *b*	HVAC system *c*	HVAC system *d*
Condensing boiler + radiant panels for space heating + split for space cooling + natural ventilation	Condensing boiler + radiant panels for space heating + split for space cooling + controlled mechanical ventilation	Water heat pump + radiant panels for space heating and cooling + natural ventilation	Water heat pump + radiant panels for space heating and cooling + controlled mechanical ventilation

6.2 Primary energy consumption

The main goal of energy evaluation was to determine the total annual energy consumption and for every single-use (space heating and cooling, domestic hot water – DHW, CMV, lighting and equipment). The energy performance was evaluated through the EnergyPlus software (www.energyplus.net). The amount of delivered energy and self-produced energy was translated into primary energy according to conversion factors (f_p) (Table IV).

The sum of primary energy produced by the RESs (ST and photovoltaic panels installed) was subtracted from total consumption in order to consider the net building primary energy delivered, according to UNI/TS 11300-2, as shown in Eqn (7):

$$Q_{p,H,W} = Q_{H,c,i} \times f_{p,i} + Q_{W,c,j} \times f_{p,j} + \left(Q_{H,aux} + Q_{W,aux} + Q_{INT,aux} - Q_{el,\exp}\right) \times f_{p,el} \tag{7}$$

where $Q_{p,H,W}$ is the global primary energy, $Q_{H,c,i}$ is the energy demand for heating obtained by each energy carrier (fuel, electricity), $f_{p,i}$ is the conversion factor for energy carrier i, $Q_{W,c,j}$ is the energy demand for DHW obtained by each energy carrier, $f_{p,j}$ is the conversion factor for energy carrier j, $Q_{H,\mathrm{aux}}$ is the electric energy demand for heating, $Q_{W,\mathrm{aux}}$ is the electric energy demand for auxiliary service for DHW, $Q_{INT,\mathrm{aux}}$ is the electric energy demand for renewable source auxiliary service, $Q_{el,\mathrm{exp}}$ is the exported electric energy by the system and $f_{p,\mathrm{el}}$ is the conversion factor for auxiliary electric energy.

The primary energy consumption was included in MCDA analysis as primary energy consumption per year divided by net-conditioned floor area ($\mathrm{kWh/m^2y}$).

6.3 Market value

In this case, the market value quotations of the municipality of Livorno Ferraris provided by the Real Estate Observatory of the Italian Cadastral Agency were considered. In particular, the minimum value was attributed to low energy performance alternatives while the maximum value has been attributed to very high-energy performance alternatives, corresponding to the classes A and A+. Indeed, recent studies in the Italian real estate showed that consumers tend to appreciate the energy rating of buildings only for the highest energy efficiency class while they do not differentiate their preference for the other classes (Bottero *et al.*, 2018a; Sdino and Magoni, 2018).

6.4 CO_2 emissions

To assess the environmental impacts, many studies use life cycle assessment (LCA) methodology that takes into account the whole life cycle of the case investigated (Azari *et al.*, 2016). LCA is a specific tool to evaluate how the building (Pombo *et al.*, 2016; Sesana and Salvalai, 2013) or their components (Babaizadeh *et al.*, 2015) contribute to the negative impacts on the environment. The LCA method is prescribed by UNI EN ISO 14040/44:2006 and the European Commission (EC) for Standardization developed EN 15970 as the standard for using LCA in the assessment of the environmental performance. In order to include environmental impacts in LCA, a monetary translation of emissions need. On the contrary, in this study in order to evaluate the negative environmental impact, the CO_2 equivalent

Energy carrier	f_p
Natural gas	1.05
Electricity supplied from the grid	2.42
Solar thermal energy	1.00
Photovoltaic energy	1.00

Table IV. Primary energy conversion factors (DM 26 June 2015, (Ministry of Economic Development, 2015)) emissions were quantified from the consumption data (primary energy) throughout the life cycle. Through CO_2 emission factors $k_{em,l}$ given by the Italian Standard UNI/TS 11300-4 for each energy carrier, the produced CO_2 ($kgCO_2/kWh$) was calculated by Eqn (8):

$$M_{del,lCO_2} = Q_{del,l} \times k_{em,l} \tag{8}$$

where M_{del,lCO_2} is the CO_2 amount of energy carrier, $Q_{del,l}$ is the specific non-renewable energy demand for energy carrier, $k_{em,l}$ is the corresponding CO_2 emission factor (Table V).

The environmental performances were calculated for the energy vectors of each alternative and included in the MCDA analysis expressed in tons per year divided by net area conditioned t/m^2y.

6.5 Indoor comfort

Energy efficiency interventions aim to improve the energy characteristics of buildings. They could determine an increase in indoor comfort reached inside buildings (Becchio *et al.*, 2019b, c). Indoor comfort could be given by the air quality and thermal, acoustic and visual comfort. These factors are assessed by environmental certifications (Asdrubali *et al.*, 2015), which want to ensure more integrated planning and at the same time, higher welfare for the occupants of residential and office buildings (Altomonte and Schiavon, 2013; Lee and Guerin, 2010). Attention to the inclusion of the comfort parameter in the feasibility assessments is becoming interesting, given the continuous updates of the relevant European standards (European Commission, 2018).

The indoor comfort indicator used in this research is the "Time Not Comfortable" based on Simple ASHRAE 55-2004 and calculated through EnergyPlus software. This index shows how many hours per year that space is not comfortable when it is occupied. This value was included in the MCDA analysis as the sum of uncomfortable hours in the year (hrs). The indoor comfort criterion importance has been highlighted by the alternatives evaluation findings due to the possible strong influence (Becchio *et al.*, 2019a). In particular, it is necessary to emphasise the range of specified uncomfortable hours (the interval between the maximum and minimum values) equal to 1,633 hrs that requires the inclusion in the analysis.

6.6 PROMETHEE II modelling

The following step of the PROMETHEE method consists in modelling the evaluation criteria according to specific preference functions. Table VI details the input parameters for the impact matrix, including the evaluation criteria, the direction of preference, the preference function with the related thresholds and the performance of the alternatives according to the considered criteria. Amongst the methods available for the weight of the criteria, the direct method was chosen for this research. Indeed, the aim is to evaluate different alternative scenarios by taking into consideration the point of view of different actors with conflicting interests. Direct rating is probably the most straightforward method available for estimating criteria weights (Ribeiro *et al.*, 2013). Specific focus groups with multidisciplinary experts were developed to assign numerical values to the different criteria and to define preference functions and the level of difference. The expert team was constituted of practitioners and

Table V.
CO_2 conversion factors (Source: UNI/TS 11300:4, 2014)

Energy carrier	$k_{em,l}$($kgCO_2/kWh$)
Natural gas	0.1998
Electricity supplied from the grid	0.4332

	Global cost (€/m^2)	Primary energy consumption (kWh/m^2)	Market value (€/m^2)	CO_2 emissions (t/m^2)	Time not comfortable (hrs)
Direction of preference	Minimize	Minimize	Maximize	Minimize	Minimize
Preference function	Linear	Usual	*U*-shape	Usual	Linear
Indifference threshold	q = 10 €/m^2	n/a	q = 400 €/m^2	n/a	q = 18 hrs
Preference threshold	p = 20 €/m^2	n/a	n/a	n/a	p = 100 hrs
1*a*	2,354	113.60	900	21.90	6,476
1*b*	2,288	87.10	900	16.90	5,880
1*c*	2,008	40.70	900	12.50	6,386
1*d*	2,039	32.10	900	6.20	5,804
2*a*	2,051	79.10	900	15.40	5,806
2*b*	2,040	55.80	900	14.40	5,140
2*c*	1,947	14.20	1,350	2.60	5,789
2*d*	2,007	5.60	1,350	1.10	4,843
3*a*	2,067	71.60	900	14.10	5,738
3*b*	2,034	49.20	900	10.60	5,335
3*c*	2,039	7.30	1,350	2.30	5,706
3*d*	2,097	0.030	1,350	0.40	5,130
4*a*	2,026	65.20	900	12.90	6,404
4*b*	2,020	45.60	900	9.20	5,990
4*c*	2,048	2.60	1,350	0.70	6,424
4*d*	2,112	−4.70	1,350	−0.90	6,205

Table VI. Input parameters for the impact matrix

research studies in the field of energy performance, economic investment and occupants' behaviour in order to obtain an overall point of view.

By reference to the definition of preference functions, for quantitative criteria "Global Cost" and "Time not comfortable" the "Linear function" was chosen. The linear function allows for fixing indifference (q) and preference (p) thresholds. In particular, for "Global Cost" criterion an expert in the economic field was consulted which chose $q = 10€/m^2$ and $p = 20€/m^2$ thresholds. For "Time not comfortable" an expert in occupants' behaviour selected q=18 *hrs* and $p = 100$ *hrs* thresholds. For the "Primary energy consumption" and "CO_2 emissions", the "Usual function" was chosen by energy efficiency and built environment expert, respectively. The decision-makers did not express a preference judgement between criteria values and then the lower criterion value is the better project performance. Finally, for the "Market value" criterion a real estate evaluator decided to apply a "U-shape function", where the indifference threshold (q = 400 €/m^2) represented the upper preference limit.

6.7 Multiple decision scenarios

Two different multi-criteria models have been developed in this study. The first model analyzes the different alternatives according to the points of view of different actors. The multi-actor analysis is grounded in recent studies developed in the literature that have identified different user profiles, characterized by a different structure of preferences (Bottero *et al.*, 2018a; Kumar *et al.*, 2019). In the second model, it was decided to change the performance of the alternative solutions about the property value criterion so as to be able to explain the spatial phenomena related to energy efficiency appreciation. Indeed, the importance of localisation in determining property values is widely recognised by the literature (Anselin, 1988; LeSage and Pace, 2008).

6.8 Multi-actors' analysis

Different scenarios considering the existence of multiple actors that give different importance to the considered evaluation criteria were simulated. As previously mentioned, personal interviews with experts in different fields were done in order to design different actors' choice profiles through the direct rating of the criteria.

The actors that we considered in the simulation can be described as follows, whereas the assigned weights for each criterion is shown in Figure 3:

(1) "Balanced actor": this is an actor for which the five aspects of the decision problem are equally important.

(2) "Traditional actor": this is a short-sighted actor who pays more attention to the usual aspects of the decision problem, such as the investment cost and the incomes; in this case, the weight of the global cost and the market value are equal to 35 per cent while the primary energy consumption, CO_2 emission and indoor comfort weight 10 per cent.

(3) "Cost-optimal actor": this is the point of view of the cost-optimal analysis, where the market value, CO_2 emissions and indoor comfort have little importance and the only criteria are the global cost and the primary energy consumption, which have the same importance in the decision process (value equal to 35 per cent).

(4) "Smart actor": this is the point of view of a "green" actor, who pays great attention to the environmental aspects of the problem; in this case, the primary energy is a crucial

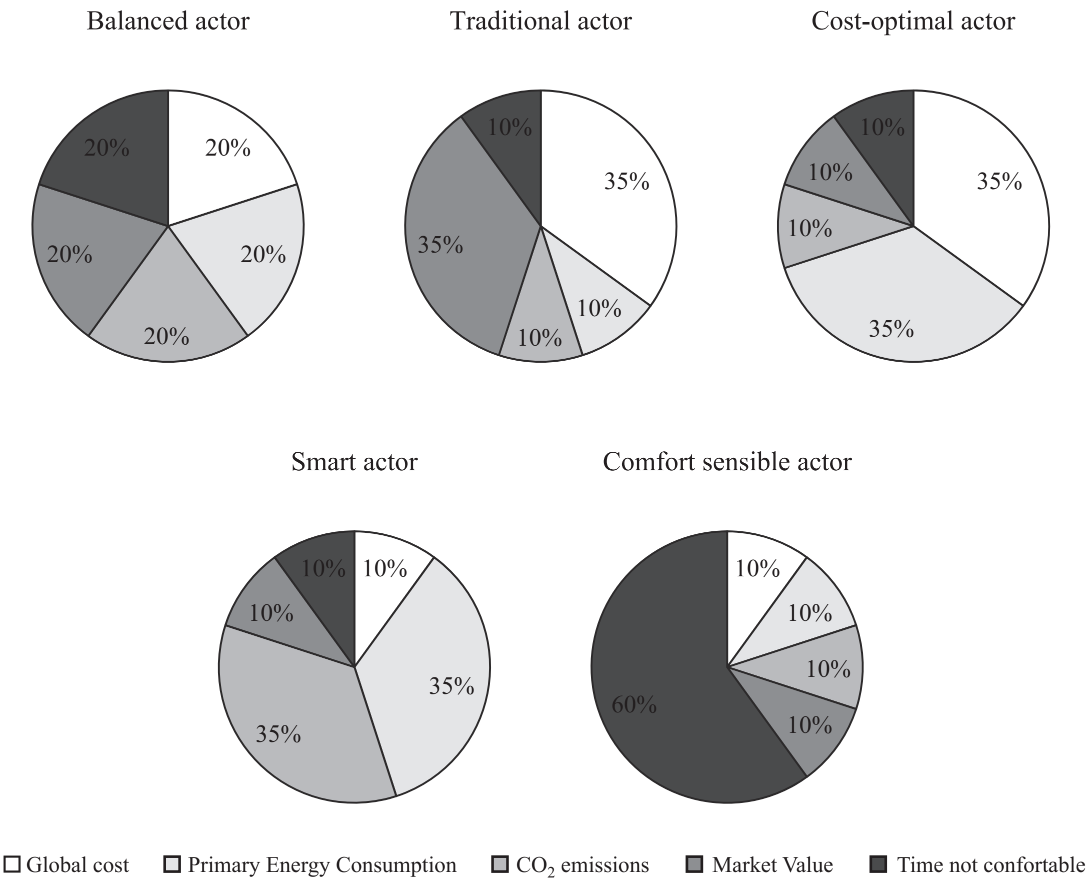


Figure 3.
Criteria weights for each actor involved

issue as the higher the energy consumption, the higher the environmental impact of the building and the higher is the energy cost over the time. In this case, the primary energy consumption and CO_2 emissions weight equal to 35 per cent while the global cost, market value and indoor comfort have a weight equal to 10 per cent.

(5) "Comfort sensible actor": this represents the user that not paid attention to money in order to ensure himself the best indoor comfort conditions, in particular, the thermal one. Then, the indoor comfort is the only criterion taken into account, with a value equal to 60 per cent, while the other ones have the same minor importance (value equal to 10 per cent).

The PROMETHEE II application produced a net flow **Φ** that allows generating a ranking of the 16 alternatives scenarios, as represented in Figure 4. The calculation performed with the use of the software Visual PROMETHEE (www.visualdecision.com).

According to the "Balance actor" shown in Figure 4, the scenarios 2*d*, 3*d* and 2*c* are ranked at the first places whereas the solutions 1*a*, 1*b* and 2*a* are always ranked at the last places. The alternative 2*c* allows obtaining good results in terms of emissions and primary energy consumption with a relatively low overall cost. A high level of indoor comfort is guaranteed by the 2*d*. While the alternative 3*d* has high performance from an environmental point of view. The alternatives 1*a*, 1*b*, 2*a* use conventional HVAC systems that fail to achieve the performance of the most innovative efficiency measures, producing high levels of emissions, requiring high costs throughout the life cycle and not guaranteeing adequate comfort conditions. The alternative 2*b* that is the best performing for indoor comfort is very appreciated by the "Comfort sensible actor" in contrast to others. Moreover, this actor gives great importance to better indoor comfort conditions (65 per cent) that affects positively (2*b*, 3*a*, 3*b*) or negatively (2*c*, 4*c* and 4*d*) the alternatives' ranking. The alternative 4*c*, which is always evaluated in the first five positions by all the actors, for the actor who is attentive to comfort, falls into the group of the worst, given the high number of hours of discomfort. While the alternative 2*b*, in 11th position for all the actors because it is less effective from the

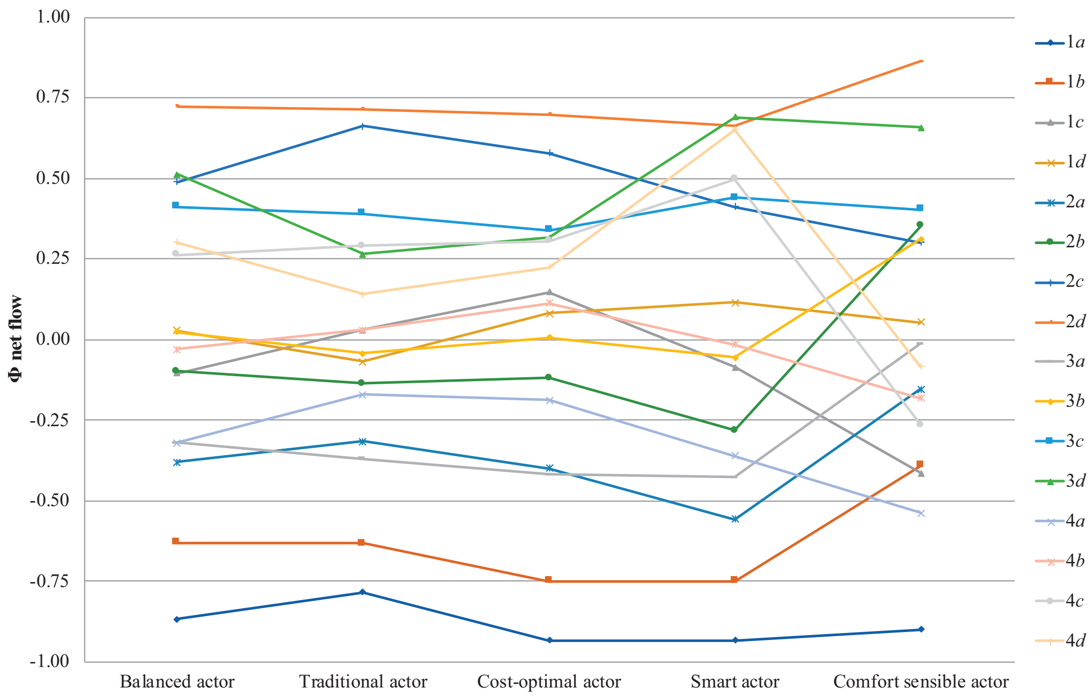


Figure 4. Ranking of the alternative systems resulting from the application of the PROMETHEE method for the case of Livorno Ferraris

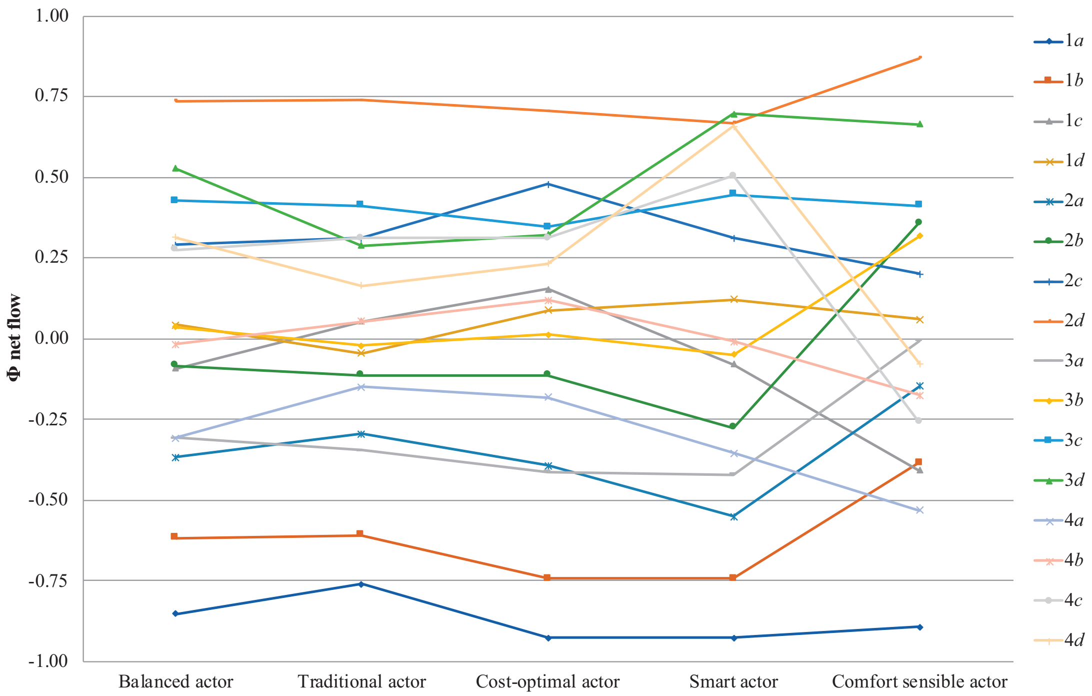


Figure 5.
Ranking of the alternative systems resulting from the application of the PROMETHEE method for the case of Torino

environmental and energy point of view, rises to the fourth position according to "Comfort sensible actor". The "Smart actor" weights rank the 3*d*, 2*d* and 4*d* alternatives, which employed a large share of RES, at the first positions. These results reflect his attention to energy savings and environmental impacts reductions. The "Traditional actor" does not appreciate the alternative 3*d* as the other profiles. Despite the benefits in terms of real estate value, 3*d* solution requires a higher global cost than the other solutions.

6.9 Multi-site analysis

The second model aims to consider the location effects of real estate market, in order to test the replicability on the market of particular efficiency measures which characterised the high-efficiency buildings in different urban contexts (Bottero *et al.*, 2018b, c; Dell'Ovo *et al.*, 2018). In detail, we performed a second decision scenario assuming a different location of the building under examination. In this case, we considered a building located in a semi-central area of the city of Torino, instead of considering the municipality of Livorno Ferraris, where the building is placed. We have thus modified the performance of the 16 alternatives of the "Market value" criterion, considering new information related to Turin's real estate market. As in the previous case, we have identified a maximum real estate value per square metre and a minimum value. The values identified were assigned to the packages based on the energy performance obtained, 4,222 €$/m^2$ as maximum and 3,167 €$/m^2$ as the minimum value, respectively. Moreover, another assumption was made about that the real estate market of a medium city is more prepared to the appreciation of energy performing building, then we attributed the maximum quotations only to those systems related to the A+ energy class. In order to allow the comparison of the outcomes of the two experiments and to discover the location effect of the NZEB building both in the urban and rural context, the weights of the criteria remained unchanged.

The results of this second experiment are represented in Figure 5. For the balanced actor, the best solutions remain unchanged. It is interesting to notice that the 4*d* alternative, a positive energy building, gets the fourth position given the appreciation in the real estate

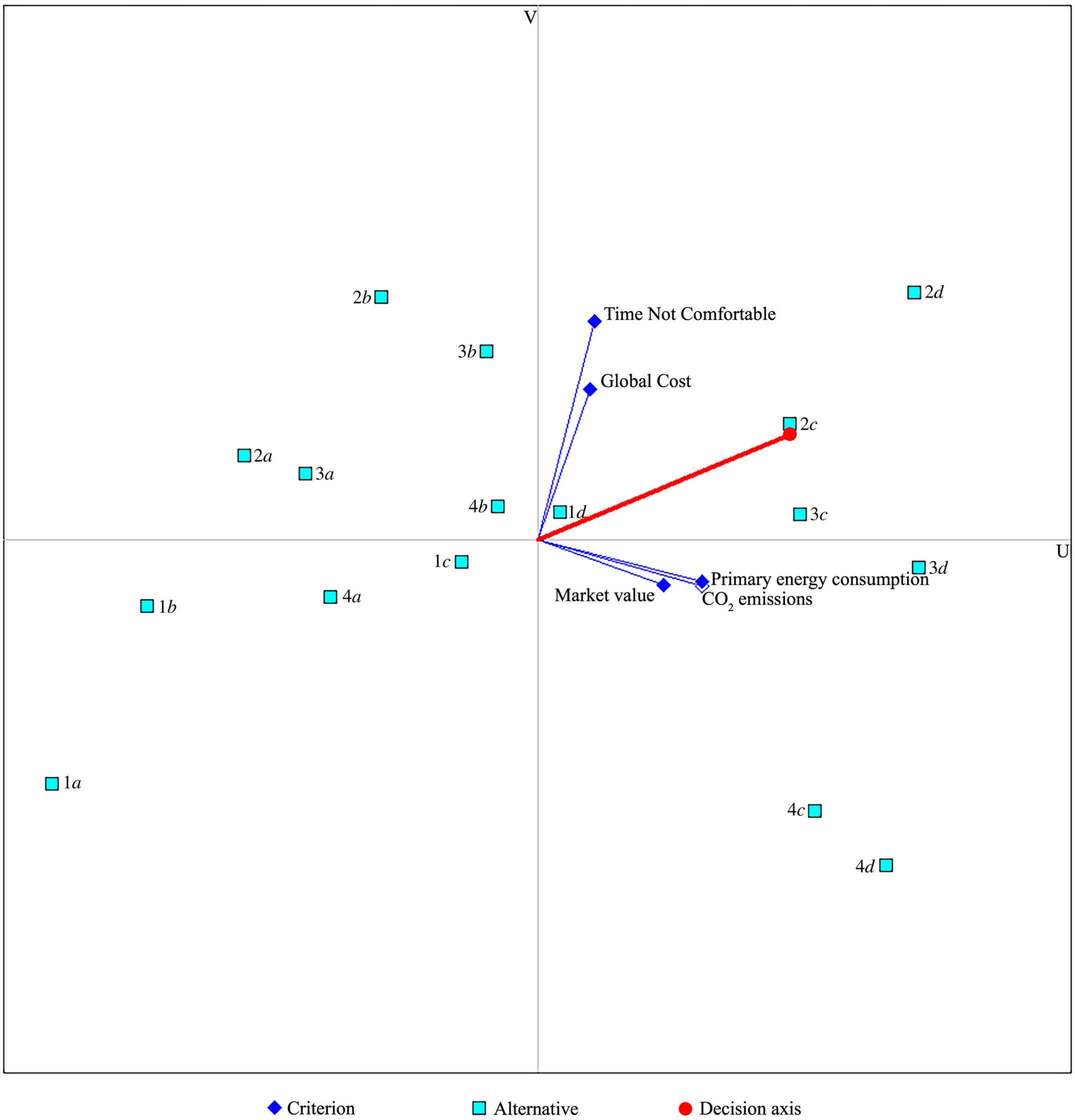


Figure 6.
GAIA analysis for the "Balanced actor" in the Livorno Ferraris scenario

market. As it is possible to see, for an operation located in the city of Torino and considering the "Traditional actor", the solution 2*d* remains the best performing. While the alternatives 2*c* and 3*c* rise to the first position.

7. Discussion of the results

The use of the GAIA plane provides valuable information in addition to the PROMETHEE rankings. Alternatives are indicated by points, while criteria by axes. This two-dimensional representation of the problem displays the relationships between alternatives and criteria or alternatives and scenarios indicating strong and weak features of the alternatives.

Firstly, it is interesting to observe the relationships between alternatives and criteria. As an example, Figure 6 shows the results for the "Balanced actor" for the building located in Livorno Ferraris. As it is possible to see, for this actor, there is a divergence of criteria directions between global cost, on the one side, and primary energy consumption and market value, on the other side. Alternative 1*c* has positive features in terms of global cost, solutions

3*d* and 4*d* are good for market value, but this is the only useful feature while alternatives 2*c* and 2*d* are the most central ones.

Secondly, it is useful to examine the results on the GAIA plane considering the relationships between alternatives and decision scenarios for the case of the building located in Livorno Ferraris and for the case of the building located in the city of Torino (Figure 7). Indeed, given the replication of the case study as an example of NZEB best practice, the added real estate value becomes an increasingly important criterion in the analysis (Dell'Anna *et al.*, 2019a). Moreover, this investigation represented a sensitivity analysis to test the robustness of the model results and the criterion input data. It is possible to notice that the "Balanced", "Traditional", "Cost-optimal" and "Smart" actors are perfectly aligned both in the case of Livorno Ferraris and Turin. In both cases, the four axes representing the actors are oriented to the right, thus showing a very moderate conflict amongst them. While "Comfort sensible actor" diverges compared to others. The decision axis representing the decision of the compromise resulting from the different actors shows that the preferred solution is *2d* both for Livorno Ferraris and Turin. Even if the "Market value" criterion does not influence the output for the best solution, it is possible to notice how it strongly changes the ranking of alternative *2c*. These results put in evidence the role of the benefits related to the asset value in the decision-making process since it is not considered in the

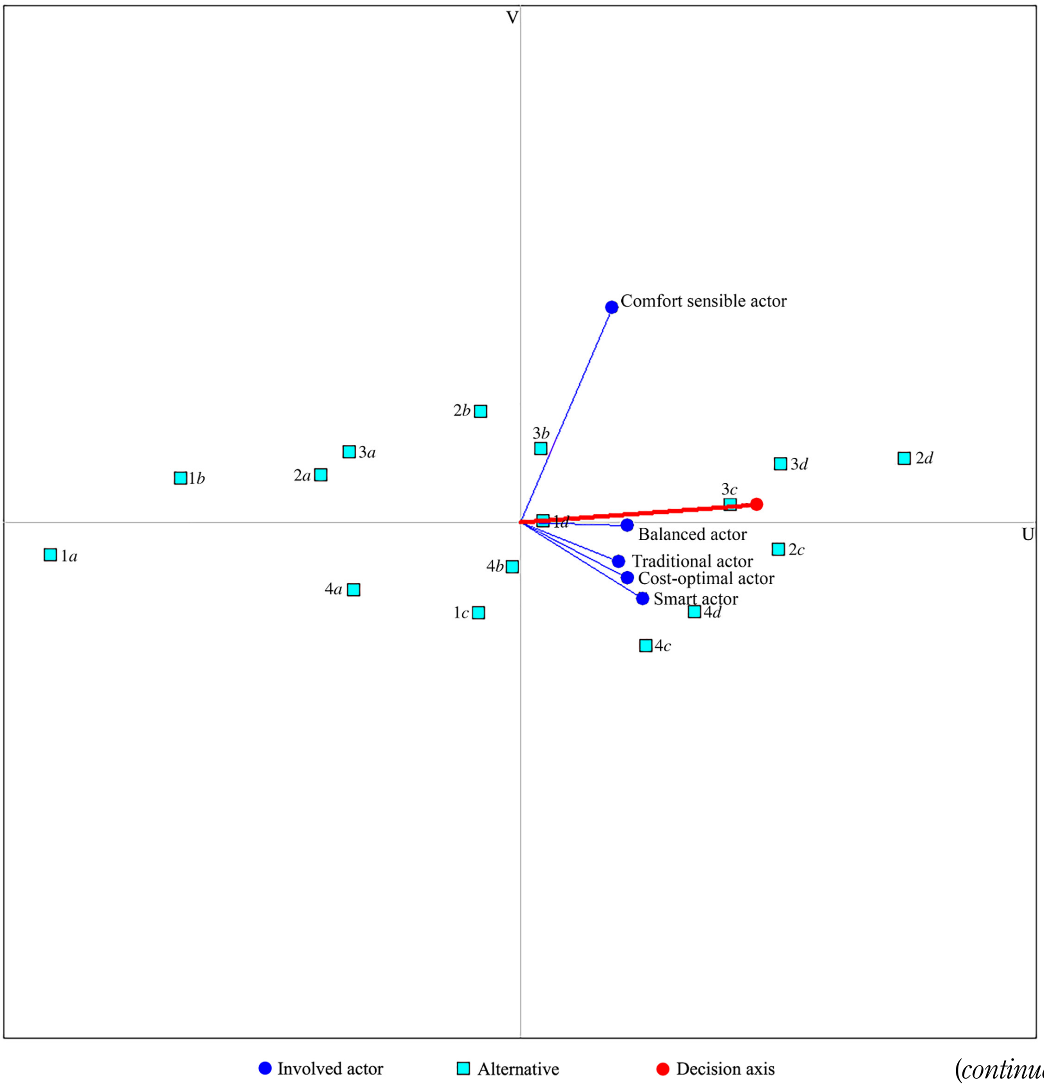


Figure 7.
GAIA analysis of the considered decision scenarios in Livorno Ferraris (top) and Torino (bottom)

(*continued*)

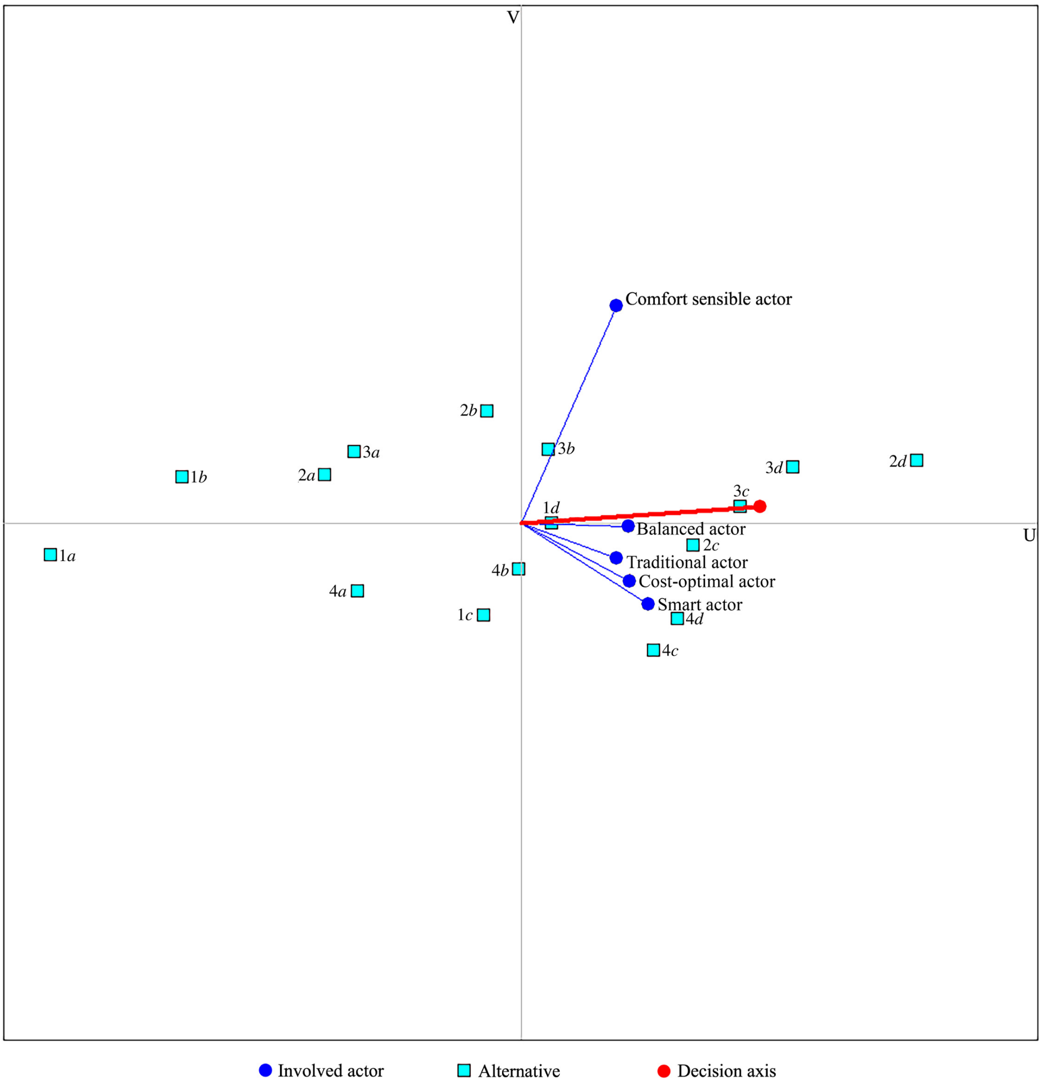


Figure 7.

traditional cost-optimal analysis. As can be seen from Figure 7, for the Turin case, the 4*d* alternative, which provides the most innovative and efficient solutions, approaches the "Smart actor". The 2*c* moves towards the "Balanced" and "Cost-optimal" actors, who pay more attention to the real estate value than the other users.

Sensitivity analyses were performed to identify the sensitivity of criteria weights and test the robustness of outcomes. By checking the stability range for each criterion considered in the assessment, it is possible to perform the sensitivity analysis. It is essential to develop sensitivity analysis for uncertain and derived by database variables, such as "Global Cost" and "Market value" ones. In Table VII, the stability intervals are shown and indicate the range in which the criterion weight changes without affecting the outcome for the "Balanced actor". The first column of the table includes the criterion. The lower bound, the weight granted and the upper bound of the criterion's weight are shown in the second, third and fourth columns, respectively. The "Market value" and "Time Not Comfortable" criteria result are the variables with a broader range.

For "Global Cost" criterion, the stability range is shown in Figure 8. The horizontal axis represents the weight of the "Global cost" criterion, while the vertical axes represent the net flow ranking, $\Phi(a)$. The criterion weight ranges from 0 per cent to 100 per cent, and the alternatives are fitted to the considered criterion. Since the net flow score is proportional to the criterion weight, grey lines show the ranking variation for each alternative. Two dotted vertical lines show the weight interval within which the best alternative remains unchanged, 2*d* alternative in our case. The vertical black bar corresponds to the current weight of the "Global Cost" criterion (20 per cent). The intersection points between alternative lines (grey lines) and the current weight bar (black bar) give the complete scores of PROMETHEE II. The black bar in the horizontal axis indicates the stability interval range for the investigated criterion in per cent terms (5.69÷58.36). The 2*d* alternative registers an almost silent ranking variation associated with changes in the weight value. While 3*d* and 4*d* alternatives go down if the "Global Cost" criterion weight increases (since they are the most expensive) while the ranking of the 1*c* and 4*b* increases (they are the cheapest ones).

Table VII.
Visual stability intervals to test stability level for the "Balanced actor"

Criterion	Min weight %	Weight granted%	Max weight%
Global cost	5.69	20	58.36
Primary energy consumption	0	20	55.18
Market value	0	20	100
CO_2 emissions	0	20	55.18
Time not comfortable	0	20	100

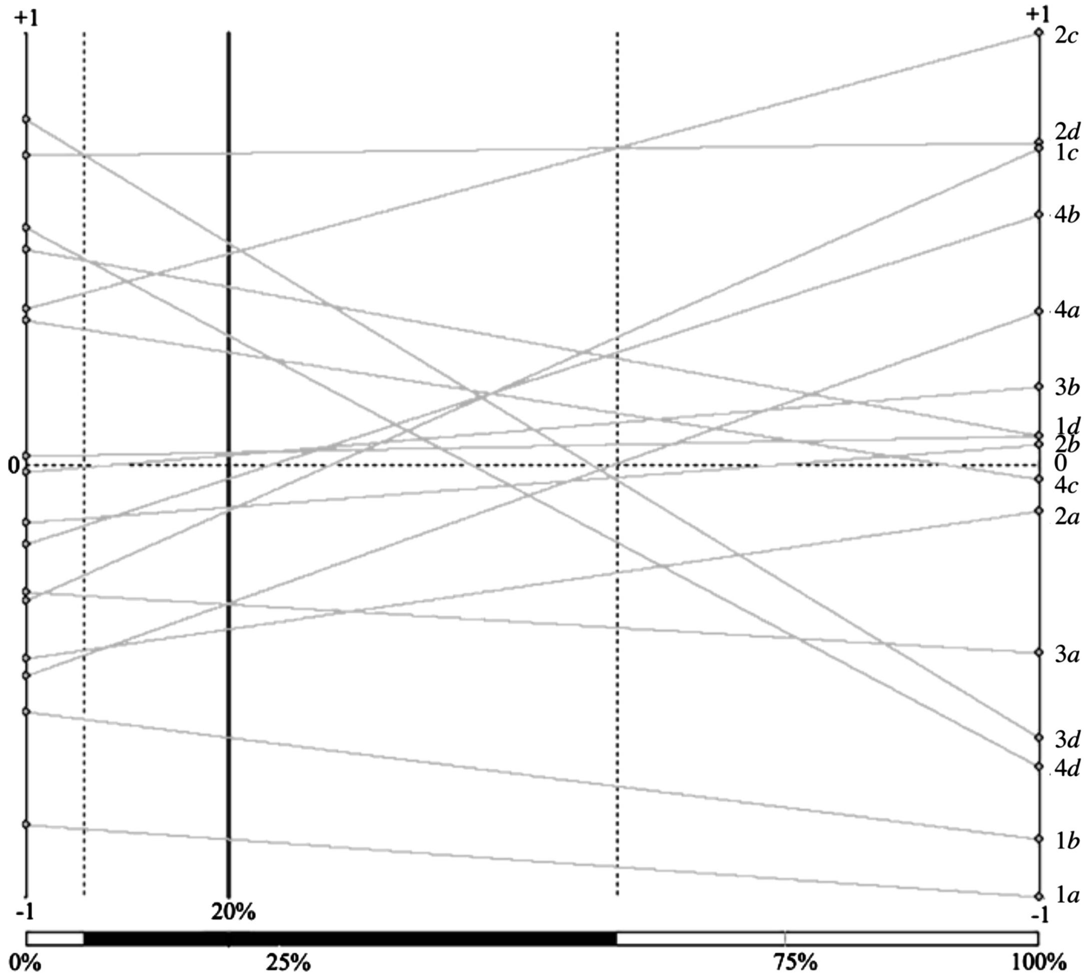


Figure 8.
Visual stability intervals of "Global Cost" criterion for the "Balanced actor"

8. Conclusions

Following the new perspectives of the United Nations, the 17 SDGs provide the guidelines for new developments that should aim to tackle climate change and build a healthy environment by the year 2030. In particular, the goals 3, 7 and 11 aim at making cities and human settlements inclusive, safe and durable from a sustainable perspective. The sustainability objectives are integrated with the European Directives that establish the minimum energy requirements for new buildings that will be built from 2020 onwards: that is the NZEB.

Moreover, the latest EBPD recast of 2018 (European Commission, 2018) provides that more considerable attention should be paid to the evaluation of the indoor conditions of buildings and its maximization. The change of point of view is clear, and new tools are needed to guide the decision-making choice, including energy and economic criteria and extra-economic aspects (Becchio *et al.*, 2017b; Bottero *et al.*, 2020a). In this perspective, designing and understanding the building system is crucial for promoting a sustainable city and a resilient society (Bottero *et al.*, 2019d, e). The study in this paper fits into this new scenario by presenting an MCDA model for the integration between cost-optimal methodology and market evaluation in order to produce a decision support system able to assists architects, engineers and planners in energy planning of NZEB, during the preliminary design phase in different urban contexts.

The PROMETHEE-based model helped to define the best energy integrated solution for a real case study located in a rural Italian area according to five evaluation criteria. The use of the MCDA method allowed ranking 16 retrofitting measures and selecting the best performing one considering four different potential actors with different visions and preferences. In the second part of the study, the extra-economic effects generated by the energy investment based on the location were investigated.

The results of the MCDA evaluation suggest discarding the solutions based on conventional technologies, in favour of the most innovative and green alternatives. The study highlighted how solutions based on system electrification scenarios using water heat pumps and PV implementation, coupled with good insulation of the building envelope, can guarantee good performance by maximising positive impacts and minimising costs.

The consideration of the full range of non-economic impacts made it possible to justify the high costs of the initial investments. In this sense, a traditional cost-optimal assessment based on the financial aspects of the operation would not have considered co-benefits generated by the investment.

The analysis proved that such an approach is able to address the complexity of the decision-making problem under examination. Besides, the results of the PROMETHEE technique for this particular problem show the numerous advantages of the method.

It could also be interesting to explore the use of other MCDA methods (i.e. ELECTRE method) in combination with the cost-optimal analysis, with specific attention to the examination of the interactions between evaluation criteria (Bottero *et al.*, 2015) and the use of multiple criteria hierarchy models.

This study highlights the necessity to implement the traditional cost-optimal approach with new evaluation criteria, according to new European policies and consumer requirements. As mentioned before, the attention to avoiding CO_2 emissions will guide the energy policies in the years to come, guarantying high indoor comfort levels to the consumer. On the other hand, it is necessary to guarantee an economic return through the added value given by the energy efficiency measures to real estate property (Bottero *et al.*, 2019a).

More generally, it would be useful to expand the approach proposed in the present paper in the domain of economics of NZEB in order to provide evidence for supporting the definition of national policies in the field of energy requalification operations and for better investigating the link between housing affordability and energy efficiency.

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