Supporting public decision process in buildings energy retrofitting operations: the application of a Multiple Criteria Decision Aiding model to a case study in Southern Italy

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Abstract

The challenge of promoting sustainable cities and reaching the objectives developed by the European Green Deal includes the renovation of the building sector, as it is responsible for 40% of energy consumption In Europe. Regional or local public administrations have to allocate their financial resources for improving the energy performances of their building stock and to face a multidimensional problem, where different aspects - such as energy efficiency, financial-economic feasibility and environmental protection - have to be harmonized. The present study proposes a Multiple Criteria Decision Aiding model, which includes the ELECTRE TRI-nC method, for supporting the public decision process of sorting alternative energy retrofitting actions into various categories, each of them expresses different levels of overall performance. The model is applied to an Italian real case study. An experts' panel has been involved for structuring the decision problem and discussing the results. The results show that opaque envelope insulation actions are often classified in best categories to be implemented and funded instead the upgrade of the lighting system falls in the worst category. These results are useful for local or regional public administrations to select those energy retrofitting actions that have to be financed as a priority.

Keywords

Public decision process, public buildings, sustainable city, energy retrofit, Multiple Criteria Decision Aiding, ELECTRE TRI-nC

1. Introduction

In 2015, more than 150 international leaders met at the United Nations to identify undeniable goals to promote human well-being and protect the environment. The community of states has approved 17 Sustainable Development Goals (SDGs), which aim to end poverty, fight against inequality and social and economic development on that occasion. The SDG11 strongly reiterates sustainable development to tackle climate change and build peaceful societies by the year 2030. In particular, this goal aims at making cities and human settlements inclusive, safe and durable from a sustainable perspective. The main challenge is to keep urban centres as workplaces capable of producing income without damaging the environment and the territory and preserving natural resources. In this perspective, designing and understanding urban systems is crucial to promote a sustainable city and a resilient society. Accordingly, improving the energy efficiency of public buildings constitute an important driving force not only for the economic aspects but also for making society more aware of sustainability issues. In this new scenario, the characterization of strategies for the energy retrofit of buildings, which aim to reduce energy consumption and promote the use of renewable energy sources (RES) has become a central issue (European Commission, 2011, 2018).

In December 2019, the European Commission presented the European Green Deal and among its key lines, 'Building and renovating in an energy and resource efficient way' is the one that can have the greatest influence on urban renewal and building refurbishment with particular attention to hospitals and school buildings. This strategy could provide also an increase of the annual renovation rate of the European real estate stock, which varies between 0.4 and 1.2% in the Member States, and furthermore is in continuity with the contents of numerous European Directives (2010/31/UE (EPBD), 2012/27/UE, 2018/844/UE, and 2018/2002/EU), which oblige Member States to renew at least every year 3% of the total floor area of buildings owned and occupied by the central government.

In recent years, a branch of academic research has focused attention on multidisciplinary studies supporting investments decisions in the context of clean energy sources and energy demand reduction actions. In this domain, a crucial role is covered by Decision Support Systems (DSS) which allow to identify the trade-off between different alternative scenarios and to select the best performing solution from the point of view of the net benefit for society. In this sense, the decision problem is not a one-dimensional issue linked only to energy issues, but it is characterized by the interaction between multi-actor and multi-level aspects of governance according to different dimensions of effects (Wang, Jing, Zhang, & Zhao, 2009). Different aspects and impacts should be considered in the decision problem, in accordance with the principles of sustainability, including important issues such as environmental protection, economic feasibility, and enhancement of historical-architectural and landscape assets. Analogously, several actors and stakeholders have to be involved in the processes, that range from public authorities, private investors, developers, practitioners, which can have different and sometimes conflicting objectives.

Traditionally, economic analysis, such as Discounted Cash Flow Analysis and Cost-Benefit Analysis, has been widely used to support public investment decisions (Gagliano, Giuffrida, Nocera, & Detommaso, 2017; Napoli, Gabrielli, & Barbaro, 2017; Nesticò & Pipolo, 2015). However, the limits of this approach in addressing urban and territorial transformations have been highlighted as they are not able to consider the overall complexity (Napoli, 2018) of the problems under investigation and they do not allow stakeholders participation into the decision-making process. In the light of the criticalities mentioned above, Multiple Criteria Decision Aiding (MCDA) approaches have become more and more important as they can include both monetary analysis and other tangible and intangible criteria expressed in physical and qualitative/quantitative terms, and to manage conflicts between social groups.

MCDA (Bouyssou, Marchant, Pirlot, Tsoukiàs, & Vincke, 2015; Figueira, Greco, & Ehrgott, 2005) indeed is a valuable and increasingly widely-used tool to support decision making, especially in complex contexts. In this perspective, it is particularly useful as a tool for sustainability assessment and urban and territorial planning (Napoli, Giuffrida, & Trovato, 2019; Napoli & Schilleci, 2014), where a complex and inter-connected range of environmental, social, and economic points of view must be taken into consideration and where objectives are often conflicting (Ferluga, Giuffrida, Napoli, & Trovato, 2016). Many applications of MCDA exist in the field of sustainability assessment, and a broad overview can be found in Munda (2016), Huang, Keisler, & Linkov (2011), Cinelli, Coles, & Kirwan (2014), and Greco & Munda (2017). Due to its flexibility and the possibility of facilitating the dialogue between stakeholders, analysts and scientists, MCDA approach is becoming very popular also in the domain of energy retrofit decision processes.

It has to be noticed that MCDA can support Decision Makers (DMs) in the main four forms of decision problems (Roy, 1981; 1987), namely choosing (to identify the best alternative or select a limited set of the best alternatives), ranking (to construct a rank-ordering of the alternatives from the best to the worst ones), sorting (to classify/sort the alternatives into predefined homogenous classes) and describing (to identify the major distinguishing features of the alternatives and perform their description based on these features).

The objective of the present paper is to demonstrate that the MCDA sorting method could be an adequate tool for supporting the decision process of Regional or local authorities in the context of a large number of energy retrofitting actions of public buildings where classification has to be made in order to allocate their financial resources. There are several reasons on the basis of the motivations of the present study. First of all, in planning the improvement of energy efficiency of a large public building stock, it usually is necessary to deal with a large dataset of energy measures and packages that have different features and are applied to buildings located in different places; in these cases, it is of particular interest for the DMs to classify the alternatives directly into appropriate groups of interventions to prioritize their funding and implementation on the basis of several criteria. Moreover, since sorting decision depends on absolute judgments that define the different groups, this procedure can be easily repeated, and new alternatives can be added at any stage of the decision process (Zopounidis & Doumpos, 1999). Finally, the application of sorting MCDA methods in the context of energy planning is limited in scientific literature, thus requiring new experimentations.

In light of the reasons as mentioned above, we propose a MCDA model to support decisions in the sorting of energy retrofitting actions for a set of public buildings located in the Apulia Region. Particularly, the ELECTRE TRI-nC (Almeida-Dias, Figueira, & Roy, 2012) method has been applied for sorting possible alternative actions for the considered stock with the aim of support public DMs in the allocation of the public financial resources to improve the energy efficiency of the buildings.

Indeed, among the MCDA sorting methods, outranking modelling framework of the type of ELECTRE methods proved to have a number of features that fit well with the problem of assessing energy investments.

For instance, this type of decision problems implies heterogeneous criteria (economic performance, energy consumptions, environmental impacts) that are measured on different scales and often characterized by imperfections in their assessment (Marzband et al., 2018; Mirzaei et al., 2019). Moreover, ELECTRE methods are based on non-compensatory approaches, thus enabling a sound sustainability assessment where a good performance on other dimensions cannot adequately compensate poor environmental performance.

In particular, the ELECTRE TRI-nC approach proposed in this paper has several advantages in comparison to other ELECTRE methods. This approach gives particular freedom to the DM in the co-construction of the decision aid model with the analysts. As he is not forced to define specific reference actions for characterizing the categories, but he is free to identify several representative actions that are appropriate to each category (Almeida-Dias et al., 2012; Doumpos & Figueira, 2019).

To the purpose of the present experimentation, an experts' panel, made up of experts in the field of energy and environmental engineering and able to express both technical and administrative expertise, has been consulted for the development of the model presented in the paper. The experts' opinion was included in the decision problem structuring. Moreover, in the final phase of the analysis, the opinion of the experts served to evaluate the results obtained from the evaluation. In particular, an interactive interview made it possible to understand whether the results obtained from the analysis were congruent with the experts' view.

The main contribution of the present paper can be thus summarized as follows:

- To examine the role of MCDA in addressing investment decisions in the context of energy retrofitting actions of public buildings at the urban or regional scale;
- To investigate the suitability of the ELECTRE sorting method to support multi-criteria classification problems in this domain.
- To study the potentiality of the ELECTRE Tri-nC approach for assessing a set of alternative retrofit measures for a real-world decision problem that involves the requalification of a stock of public buildings in the Apulian Region, focusing, in particular, on the examination of how the method can be operatively implemented by practitioners and professional operators, proving clear results that can be emplaced for guiding public or private investment decisions.

The paper is organized as follows. A literature review is explained in the next section. The third section introduces the methodological background. The fourth section presents the application of the evaluation model to the case study. The application's results were presented in Section 5. The last section contains conclusions and presents the possible future developments of the research.

2. Literature review on MCDA in the energy sector

2.1 Utility function theory approaches

MCDA-based techniques support decision process involving conflicting and multiple goals. In this perspective, the solution strongly depends on the preferences of the decision-makers (DMs) involved, and there must be a compromise. In the context of energy-related problems, MCDA (Multiple Criteria Decision Aid) applications include the analysis of the energy policies to be implemented, as well as, the choice of the most suitable technologies to be developed.

Depending on the purpose and contents of the evaluation, different MCDA methods can be used. A MCDA classification can be based on the procedure adopted to reveal the preferences (Braune, Pinkwart, & Reeg, 2009; Si, Marjanovic-Halburd, Nasiri, & Bell, 2016; Strantzali & Aravossis, 2016). A first category of the methods refers to the theory of multi-attribute utility. Among these falls the AHP (Analytic Hierarchy Process) method developed by Saaty (1980). The method derives a priority scale between the criteria and the alternatives and simplifies preference votes among the decision criteria using pairwise comparisons of criteria. AHP is a compensatory method capable of managing a certain amount of inconsistency of DM within limits deemed acceptable and sustainable by purely mathematical considerations (Zheng, Yu, Wang, & Tao, 2019). AHP is widely used in the energy sector. Ghimire & Kim (2018) used AHP methodology to estimate and classify the economic, social and political barriers for the dissemination of RES in rural and remote areas in Nepal. The AHP method was used to define the best practice priorities for public investments in sustainability in Brazilian cities (Salvia, Brandli, Leal Filho, & Locatelli Kalil, 2019). A spatial-MCDA was developed using an AHP approach to identify neighbourhoods with high vulnerability to fuel poverty in a German city, allowing to fund and support the high-risk areas (März, 2018). In recent years, hybrid models have been developed starting from the strengths of the approaches. In this context, an integrated SWOT-AHP model was developed to identify and prioritize Pakistan's energy planning and strategic policies (Solangi, Tan, Mirjat, & Ali, 2019). TOPSIS is a method no widely applied in the energy sector. The method assumes that each attribute has an increasing or decreasing utility. Thus, the order of preference for alternatives is produced by comparing Euclidean distances between different alternatives and the best and worst hypothetical alternative. Aryanpur, Atabaki, Marzband, Siano, & Ghayoumi (2019) proposes a model based on AHP and TOPSIS to assess the sustainability of future electricity scenarios for the 2015-2050 period in Iran. The scenarios are then classified based on 18 different techno-economic, environmental and social dimensions of sustainability.

The utility-based theory includes other methods that synthesize information into a single parameter (also called a performance aggregation approach) introduced in the 1970s by Keeney & Raiffa (1976). One of the methods of this family is the Multi-Attribute Value Theory (MAVT). Yilan, Kadirgan, & Çiftçioğlu (2020) uses a decision model based on MAVT to evaluate five different alternative electricity generation technologies in Turkey considering groups of economic, technical, environmental and socio-economic criteria. Neves, Dias, Antunes, & Martins (2009) proposed MAVT as a generic evaluation model when deciding about financing or implementing any energy efficiency initiative and it is necessary to consider each involved actor and its interests.

All the methods are seen so far build order of alternatives classification from the best to the worst (ranking). Models based on utility theory are to be favoured when the alternatives are limited in number.

2.2 Outranking relation methods

Widely used in the energy field are the outranking approaches supporting the decision. The outranking methods have been developed to deal with problems of choice (selecting the best alternative among others), sorting (assignment of alternatives to several categories of which the characteristics are known) and ranking (construction of an order of preference on the set of possible actions to be taken) (Becchio, Bottero, Corgnati, & Dell'Anna, 2017; Norese, 2006). This group includes the methods of the ELECTRE (ELimination Et Choix TRaduisant la REalité) and PROMETHEE (Preference Ranking Organization METHod for Enrichment of Evaluations) families. PROMETHEE methods permit to rank alternatives on the basis of pairwise comparison of alternatives on a set of considered criteria, with a methodology charatered by ease of use and reduced complexity (Brans, Mareschal, & Vincke, 1984; Brans, Vincke, & Mareschal, 1986; Mareschal & De Smet, 2009). Some recent advances in PROMETHEE methodology permits to take into account also robustness with respect to weights and interaction between criteria (Corrente, Figueira & Greco, 2014; Arcidiacono, Corrente & Greco, 2018). A model based on PROMETHEE was proposed to evaluate the environmental and extra-economic performances of a Nearly Zero-Energy Building in Italy by Dell'Anna et al., (2020). In detail, the authors evaluate 16 alternatives according to energy, economic and social criteria. Alternative transformation paths to reach a sustainable energy system in the EU have been evaluated through a multi-criteria model based on fuzzy-PROMETHEE approach (Papapostolou, Karakosta, Kourti, Doukas, & Psarras, 2019). Also, ELECTRE method focuses the analysis on the relations of the domain between the alternatives. Several ELECTRE methods differ in the problems faced (choice for ELECTRE

I, ordering for others), the nature of the data processed and therefore the type of criteria and the procedure for outranking modelling. The choice of the method is mainly motivated by indications connected both to the nature of the data available, therefore to the criteria that can be used, and to the rule of decision used. The ELECTRE method has been widely used in energy research and has proved helpful as an aid to decision making in many applications at different scales. ELECTRE III is one of the most methods applied in energy planning decision problem. Starting from the building's application scale, Catalina, Virgone, & Blanco (2011) applied the ELECTRE III method to evaluate multi-energy alternative sources for a family home located in France. The alternatives stemmed from the combination of different RES shares (photovoltaic and solar thermal panel) and different generation systems evaluated according to three criteria. Many studies have been developed in the field of RES penetration in energy-isolated case studies such as islands (Haurant, Oberti, & Muselli, 2011). In one of the first applications in the energy field, the ELECTRE III method was applied to face the problem of the growing demand for electricity on the island of Crete (Greece) (E. Georgopoulou, Lalas, & Papagiannakis, 1997). Beccali, Cellura, & Mistretta (2003) and Beccali, Cellura, & Ardente (1998) applied an ELECTRE III based model to compare three different scenarios for the implementation of RES in Sardinia (Italy) from energy, economic, environmental and social point of view. The spread of RES in the isolated complex of the Aegean islands has been investigated by Papadopoulos & Karagiannidis (2008). Extensive applications of the MCDA on the national territory have been applied in Portugal by Haydt, Leal, & Dias (2014). In detail, the study applied ELECTRE III to build national energy efficiency plans, considering multiple criteria instead of only energy savings. ELECTRE III was not applied only to evaluate the implementation of RES, but also subsidy schemes to promote a specific technology (Theodorou, Florides, & Tassou, 2010).

In the ELECTRE family of methods, there are also methods that sort alternatives in categories. The ELECTRE TRI method provides a subset of alternatives evaluated with a family of criteria (qualitative/quantitative), a set of ordered (hierarchical) categories and the assignment of the projects to these categories. In the energy field, the method has been applied mainly on a national scale where the alternatives to be evaluated are numerous. In Greece, the method was applied for the time-scheduling of sustainable measures aimed at reducing the environmental impacts of the RES, transport, industry, and energy generation sectors (Georgopoulou, Sarafidis, Mirasgedis, Zaimi, & Lalas, 2003). In Portugal, 24 alternative actions for the promotion of energy efficiency were assessed based on qualitative and quantitative criteria (Neves, Martins, Antunes, & Dias, 2008). An ELECTRE TRI spatial model was applied in Spain to classify 20 alternative locations of photovoltaic farms into 4 categories defined by three reference profiles (Sánchez-Lozano, Henggeler Antunes, García-Cascales, & Dias, 2014). Dias, Antunes, Dantas, de Castro, & Zamboni (2018) assessed smart grid policies in Brazil considering the impact on different objectives, but also the importance of these objectives forwarded by 28 experts. Few applications of the method have been developed on buildings. In Portugal, ELECTRE TRI was applied to evaluate the energy performance of the schools' building stock also considering non-energy aspects such as indoor environmental quality, thermal comfort and the occurrence of maintenance operations (Bernardo, Gaspar, & Antunes, 2017).

2.3 Paper contribution

As it turned out from the review, it is possible to confirm that several multi-criteria approaches have been applied in supporting decision problems in the energy sector. As explained above, most of the applications concerned different fields, from the single building to isolated problems, up to assessments on a national scale. If some MCDA methods provide an ordering of alternative solutions, ELECTRE TRI allows sorting alternative solutions in categories. ELECTRE TRI model is more effective when the alternatives are numerous as in decision problems of public administration domain. The review highlights that the classification of the alternative by ELECTRE TRI has rarely been applied in the academic literature in the energy sector. To the knowledge of the authors, the present paper represents the first application of the ELECTRE TRI-nC method for addressing investment decision in the context of the energy retrofit operations. This study aims, thus, to fill this gap providing empirical and practical insights into the functional characteristics of the model for the evaluation energy retrofit alternatives on a set of existing buildings. In this application, we apply the new sorting the ELECTRE TRI-nC method for the evaluation of alternative retrofitting. The ELECTRE TRI-nC method gives the possibility to consider several reference actions for characterizing each category, helping the DM in the construction of the decision problem. The case study selected for the application is a stock of public buildings located in the Apulia Region (Southern Italy). The interest in the research also lies in the fact that the Italian public building stock is characterized by inadequate envelopes and low-performance Heating, Ventilation and Air Conditioning (HVAC) systems (Iorio & Federici, 2018). For this reason, there is growing attention in assessing the energy performance of the public building stock, aiming to define appropriate energy retrofitting actions and to reduce national CO_2 emissions.

Therefore, the study represents a novelty from the point of view of the method, as ELECTRE TRI-nC was little explored in real case studies. The other novelty is represented by the case study since the management and planning of retrofit operations at building scale was poorly treated with MCDM approaches.

3. Methodology

This study proposes a global model to support DMs to sort a large set of energy retrofitting actions of buildings. The model is based on the following main steps (Figure 1):

a. Provision of a database of the building stock. The database collects information from the energy audit reports of the buildings and the proposed energy retrofitting actions, such as geometric features, HVAC systems, lighting equipment, thermophysical characteristics, Primary Energy (PE) consumptions in kWh/m^3/year, greenhouse emissions in ton CO_2/year, global energy performance, current operating costs, investment cost, etc. Moreover, information from the architectural, landscape, and environmental constraints set by urban, regional and landscape plans are also required.

b. Framework of the multiple criteria model. A study group, with the help of an experts' panel in the field of energy and engineering, structures the decision problem. The proposed evaluation model takes into account several criteria, considering three main themes: energy efficiency, financial feasibility and compatibility with the architectural, landscape, and environmental constraints.

c. *Application of the ELECTRE TRI-nC method*. The multiple criteria method is applied to the dataset of alternatives retrofitting actions.

d. Sorting of the energy retrofitting actions into categories. The output of ELECTRE TRI-nC allows to sort the energy retrofitting actions into various categories, each of them expressing a different level of overall performance. In the case of the present application, this result is useful for the DM to select those actions to be financed as a priority directly.

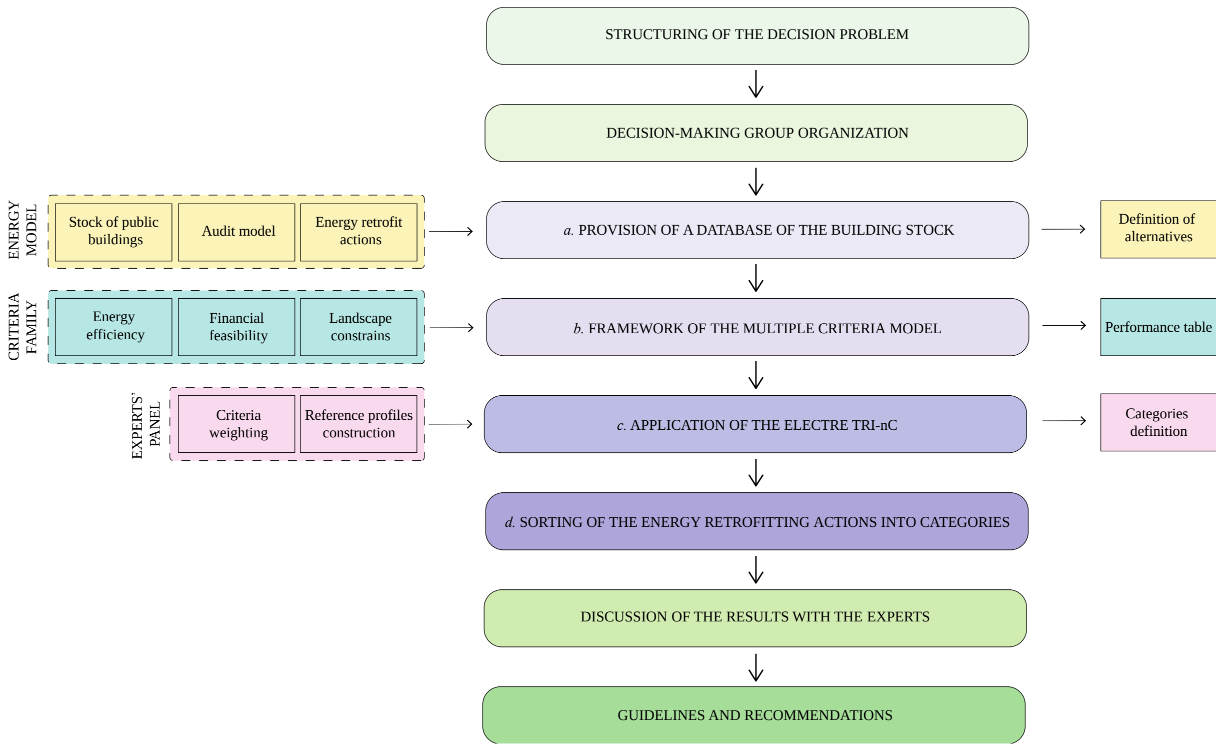

Figure 1: Framework of the model

As stated before, the main goal of the present research is to show the excellent potentials of a sorting evaluation framework for supporting decisions in the context of energy. The multiple criteria ELECTRE TRI-nC method has been employed as a recommendation tool for prioritizing a large dataset of alternative energy requalification operations.

The ELECTRE TRI-nC method belongs to the family of the ELECTRE methods (Figueira, Greco, & Ehrogott, 2005), which are characterized by modelling the preferences between alternative options by using binary outranking relations based on the concordance and non-discordance concepts. Each ELECTRE method has its construction of one or several outranking relations, which enable to formulate sound and comprehensible recommendations for the DM. More in details, ELECTRE TRI-nC is a recent decision aiding ordinal classification (or sorting) method proposed by Almeida-Dias, Figueira & Roy, B. (2012). The method follows a co-constructed approach, and it is based on a strong interaction between the analyst and the DM. The involvement of DM in each step of the decision process ensures that the preferences are correctly represented in the developed categorization model.

As previously anticipated, sorting problems refer to ordinal classification problems in which the actions must be assigned to a set of categories. This assignment is based on the characterization of each action (in our case, retrofitting measure) according to several criteria.

The basic data of a multiple criteria sorting problem can be summarized as follows: a set of alternative actions: $A=\{a_1, \ldots, a_i, \ldots, a_m\}$; a coherent family of criteria, which characterize each action: $G=\{g_1, \ldots, g_j, \ldots, g_n\}$; the performance of action a_i on criterion g_j: $g_j(a_i)$; a set of ordered categories: $C=\{C_1, \ldots, C_q\}$, where C_1 is the worst category and C_q the best one; a set of characteristics profiles or reference actions that define the categories: $B=\{B_1, \ldots, B_q\}$; a set of reference actions characterizing the category C_h: $B_h=\{B_{h1}, \ldots, B_{h[Bh]}\}$.

The ELECTRE TRI-nC method assumes that $B \cup \{B_0, B_{q+1}\}$ denote the set of $(q+2)$ subsets of characteristics profiles, such that $B = \{B_1, B_2, \ldots, B_h, \ldots, B_q\}$. Let $B_0 = \{b_0^1\}$ and $B_{q+1} = \{b_{q+1}^1\}$ denote the two particular subsets of reference profiles, such that $g_j(b_0^1)$ is the worst performance and $g_j(b_{q+1}^1)$ is the best one in terms of criterion g_j (Costa, Govindan, & Figueira, 2018).

As far as the ELECTRE TRI-nC method is concerned, it constructs a single outranking relation. The exploitation of this outranking relation consists of the procedure of assigning actions to pre-defined and ordered categories using multiple characteristics profiles for each class. The interaction between DM and analyst helps to define the boundaries profiles of categories. The procedure leads to define an interval for the assignment of every action instead of providing the DM with a single category, in accordance with the uncertainties and ambiguities that commonly affect real problems in the context of urban transformations and energy requalification operations (Doumpos & Figueira, 2019). According to other ELECTRE family methods, ELECTRE TRI-nC method makes use of veto and discrimination (indifference and preference) thresholds that allow modelling the arbitrariness and the imperfect knowledge that characterize many decision problems. Indeed, these thresholds are expressly introduced in order to take into account the imperfect character of the data from the computation of the performances of the alternatives over the criteria. These thresholds are thus technical parameters used to model the imperfect knowledge of the performances and the uncertancy that may characterize the measures.

Other important advantages of the ELECTRE TRI-nC method can be highlighted, that assume particular importance in the case of the present application. Firstly, the performance of alternatives are measured according to qualitative and quantitative criteria; secondly, it is needed to define a weight for each criterion according to its importance for the DM; thirdly, ELECTRE TRI-nC does not allow systematic compensation among the criteria and this aspect is of particular importance in the context of sustainability assessment where a good performance on another criterion cannot systematically compensate a bad performance on a certain criterion; fourthly, the method takes into account possible data imperfections and arbitrariness in the construction of the family of criteria.

ELECTRE TRI-nC method has been applied to support decision making in real-world problems, including business management, economics and finance. Mention has to be made to the fact that the present paper refers to the first application of the method in the field of energy.

4. Application

The Italian peninsula is subdivided into six Climate Zones, from A (up to 600 Heating Degree Days (HDD)) to F (over 3000 HDD) (Moreci, Ciulla, & Lo Brano, 2016; Ciulla, Lo Brano, & Moreci, 2015). Conventional time extensions of heating seasons are also defined by Italian law (D.P.R. n. 412, 1993). Apulia Region is located in Southern Italy, bordering the Adriatic

Sea, the Ionian Sea and the Strait of Otranto and Gulf of Taranto; the climate is typically Mediterranean with hot, dry and sunny summers and mild, rainy winters.

As reported by Citterio (2009), about 27% of Italian public non-residential buildings are located in Southern Italy; as far as the climatic zones are considered, 51% of them falls in the climatic zone C, 25% falls in D, and 16% are in B. A detailed analysis among geographical areas is necessary to understand the performance of the building stock. For the present research, a reliable database of the "*status quo*" of the building stock was used (Beccali, Lo Brano, Ciulla, Bonomolo, & Galatioto, 2016), which was developed within the Italian project "POI (Interregional Operative Program) ENERGIA 2014–2020" belonging to EU Horizon 2020. This database considered a sample of 36 public buildings located in six difference cities of the Apulia Region: 84% are located in Zone C, and 16% are in Zone D. The uses of the considered buildings are mainly school but also include office, sport buildings, library and university (D.P.R. n. 412, 1993).

The energy performance of the actual building stock in Apulia is obtained from the energy audit of the buildings (Beccali, Ciulla, Lo Brano, Galatioto, & Bonomolo, 2017). Generally, the building-stock is characterized by an average gross volume of 26,917 m^3 with an average surface area of 6789 $m^{2,}$ and a shape factor between the gross volume and the total loss surfaces is 1 m^{-1}. As an example, the main features of the building envelope are reported in Table 1.

Table 1: Typologies and thermophysical features of envelope elements

Envelope Element	Typology	Transmittance [W/m^2K]	Thickness [m]
External wall A	Cavity wall 1	0.659	0.54
	Cavity wall 2	0.799	0.52
External wall B	Brick block wall	1.029	0.30
Roof	Hollow-core concrete 1	1.105	0.52
	Hollow-core concrete 2	1.027	0.56
Floor	Hollow-core concrete 1	1.301	0.35
	Hollow-core concrete 2	1.891	0.27
	Hollow-core concrete 3	0.672	0.40
Window glass	Aluminium with double glass 1	3.080	
	Aluminium with double glass 2	2.970	

As far as the energy system is considered, the majority of buildings is characterized by the simultaneous presence of different typologies: space heating, cooling and hot water production. The most common heating system is the Standard natural gas boiler, or Mono split HP (Heat Pump), where the cooling system is mostly related to mono split; generally, even if the hot water production is not the priority, it is possible to find some electrical boiler. As far as the cooling system is concerned, in the 87% of the buildings, mono-splits are installed, and only in 11% the water chillers are present. The use of DHW (Domestic Hot Water) is very limited; indeed, many buildings do not have any centralized DHW systems but rather use few electrical boilers. There are not solar thermal systems, but photovoltaic panels are installed in 11 buildings.

About lighting systems, the most common typologies of lamps installed in Apulia are iodide lamp in the external space and fluorescent for the indoor space.

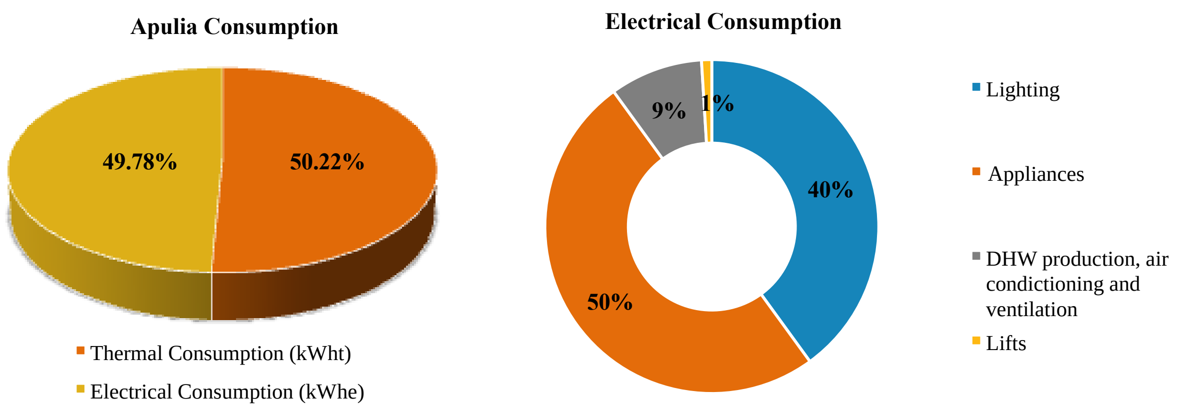

Figure 2: Energy consumptions (left) and detailed electrical consumptions (right) of the building stock

Analyzing in details the data related to the energy consumption and the energy performance of the entire building stock, it is possible to underline that the thermal and electrical consumptions have the same impact in the total consumptions (Figure 2, left). In general, the thermal consumptions can be attributed exclusively to the conditioning systems, while the electric consumptions are divided into different items, namely lighting, appliances, hot water production and lift (Figure 2, right).

4.1 Description of the problem

For the present application, 36 public buildings located in the Apulia Region were considered (D. Lgs. 19th August 2005 n.192, 2005).

As highlighted in Figure 3, these buildings, labelled B01 to B36, are characterized by a Primary Energy (PE) consumption (yellow column) higher than the limit value (red line). The average regional PE was also evaluated, and it is equal to 32.89 kWh/m^{3}year (green line) that is always higher of all each limit value.

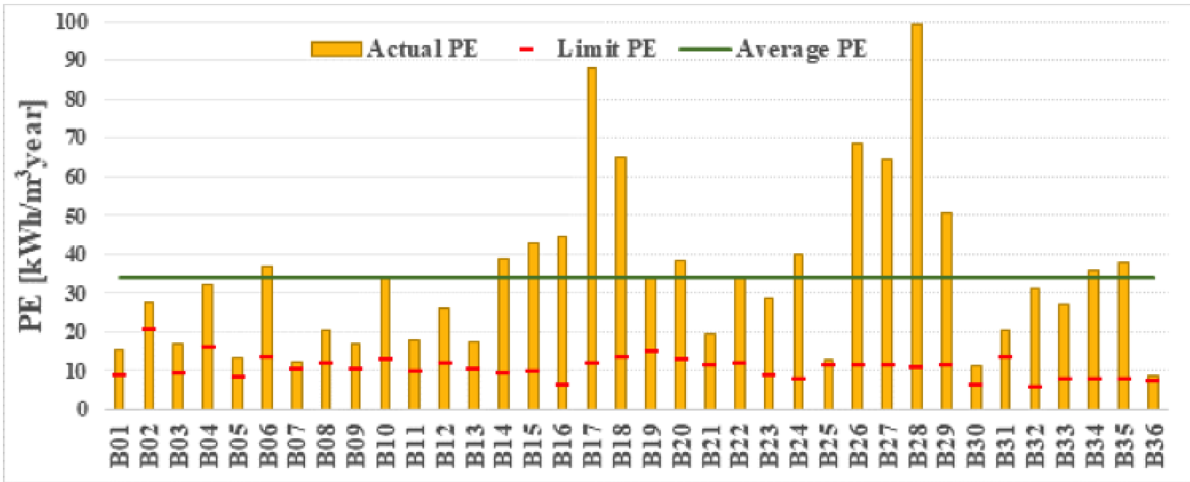

Figure 3: Primary Energy consumption of the building stock considered in the application

The alternative actions for the 36 public buildings are defined based on the results coming from the energy audit model. Eight possible typologies of retrofitting actions are considered, as reported in Table 2, and a total of 210 energy retrofitting actions are proposed, labelled A001 to A210. For each action, the investment cost is also estimated.

Table 2: Typologies of retrofitting measures

	Retrofitting actions
BM	Upgrade of building management and automation system
LS	Upgrade of the lighting system
OI	Opaque envelope insulation
HS	Upgrade of Heating, Ventilation and Air Conditioning system (HVAC)
PS	Installation of Photovoltaic system (PV)
TE	Upgrade of the transparent envelope
TR	Upgrade of thermoregulation system
SS	Solar thermal system

In general, the actions named BM, LS, OI, TE and TR are proposed for almost all buildings. The HS action is considered in 2 buildings and the BM actions in 17 buildings, whereas the effect of the installation of photovoltaic and solar systems (PS and SS) is proposed respectively for just 12 and 8 buildings. Table 3 shows the total costs of the application of all retrofitting actions in each building and the total cost of each retrofitting action in the entire region.

Table 3: Proposed retrofitting actions and estimation of the total cost for each building of the considered stock

Building	Retrofitting Actions								Total Cost [€]
	1 BM	2 LS	3 OI	4 HS	5 PS	6 TE	7 TR	8 SS	
B01	A003	A005 A006	A001	-	-	A002	A004	-	1,104,331
B02	A009	A010 A011 A012	A007	-	-	A008	-	-	164,190
B03	-	A015 A016 A017	A013	-	-	A014	-	-	1,231,083
B04	A020	A022 A023 A024	A018	-	-	A019	A021	-	802,811
B05	-	A028 A029	A025	-	-	A026	A027	-	1,205,019
B06	A032	A034 A035	A030	-	A037	A031	A033	A036	844,789
B07	A040	A042 A043 A044	A038	-	A046	A039	A041	A045	1,993,973
B08	A049	A051 A052	A047	-	A053	A048	A050	-	642,394
B09	A056	A058 A059	A054	-	-	A055	A057	-	2,171,634
B10	A062	A064 A065	A060	-	A0663	A061	A063	-	1,209,892
B11	A069	A071 A072	A067	-	A073	A068	A070	-	2,197,674
B12	A076	A078 A079	A074	-	A081	A075	A077	A080	922,697
B13	A084	-	A082	-	-	A083	A085	-	538,659
B14	A088	A090	A086	-	-	A087	A089	-	1,442,264
B15	A093	A095	A091	-	-	A092	A094	-	2,529,912
B16	A098	A100	A096	-	-	A097	A099	-	1,658,587
B17	A102 A106 A110	A104 A108 A112	A101 A105 A109	-	-	-	A103 A107 A111	-	2,077,105
B18	A115	A118	A113	-	-	A114	A116	A117	567,610
B19	A121	-	A119	-	-	A120	-	-	1,047,079
B20	A124	A127	A122	-	-	A123	A125	A126	1,603,965

B21	-	A131	A128	-	-	A129	A130	-	1,016,001
B22	-	A135	A132	-	-	A133	A134	-	2,660,874
B23	-	A139	A136	-	-	A137	A138	-	1,973,270
B24	A142	A144	A140	-	-	A141	A143	-	992,469
B25	A147	A148 A149	A145	-	-	A146	-	-	1,660,542
B26	A152	A154 A155	A150	A158	A157	A151	A153	A156	940,533
B27	A160	A160	A160	A160	A160	A160	A160	A160	929,991
B28	-	-	A168	-	-	A169	-	-	431,195
B29	A172	A174 A175	A170	A209	-	A171	A173	A176	923,366
B30	A179	A181 A182 A181	A177	A210	-	A178	A180	-	1,356,948
B31	A185	A187	A184	-	-	-	A186	-	397,527
B32	A188	A190	-	-	-	-	A189	-	298,027
B33	A193	A195	A191	-	-	A192	A194	-	681,027
B34	A198	A200	A196	-	-	A197	A199	-	2,028,333
B35	A202	A204	A201	-	-	-	A203	-	867,573
B36	-	A208	A205	-	-	A206	A207	-	2,614,067
Total cost	2,216,391	3,076,101	25,712,823	990,500	800,000	11,692,391	906,294	253,820	45,736,320

Figure 4 shows, for example, the ante and post retrofitting actions Primary Energy consumptions (PEs) for the action Opaque Envelope Insulation (OI).

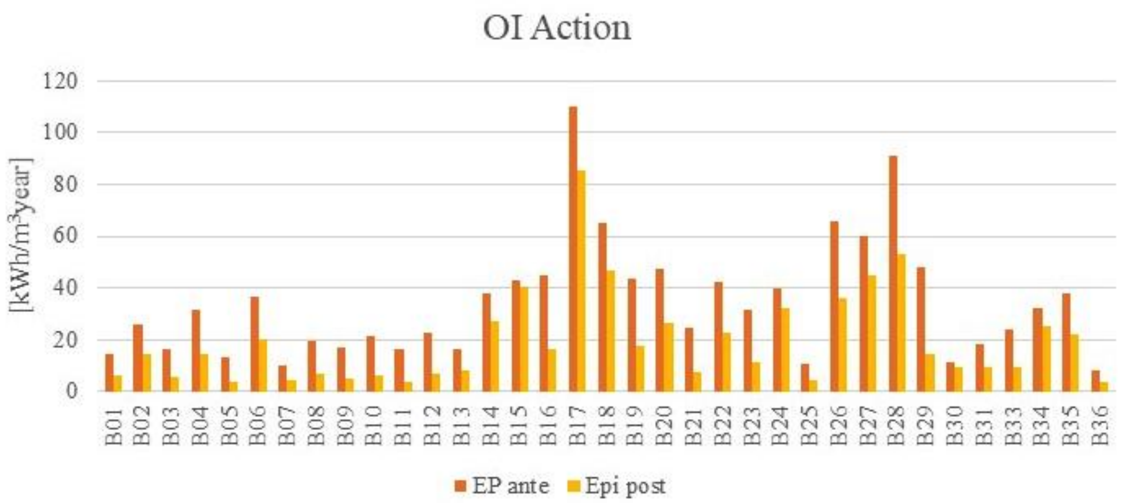

Figure 4: Primary Energy consumptions ante and post retrofitting actions

4.2 Constructing the family of criteria

The decision problem under investigation has been structured with the help of an experts' panel in the field of energy and engineering. To build the multiple criteria model according to the three main thematic issues previously defined in section 3, eight criteria have been defined and submitted to the experts' panel review (Figure 5).

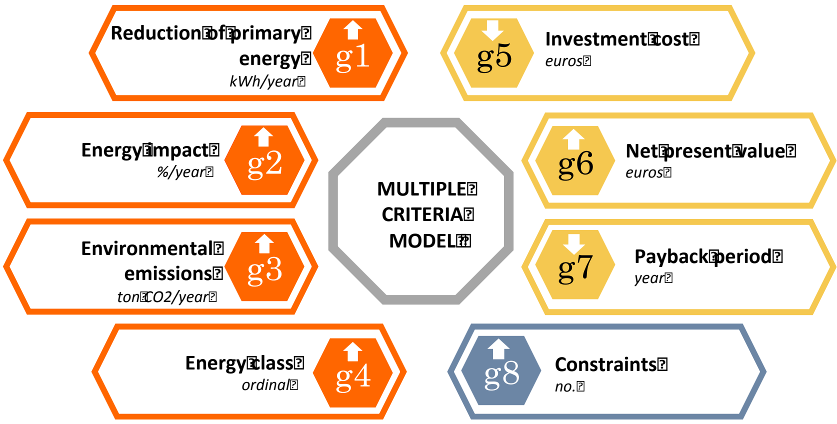

Figure 5: Multiple Criteria Model

The first subset of criteria, from *g1* to *g4*, considers the energy efficiency of the retrofitting measures.

1. In particular, the criterion g_1 *Reduction of primary energy*, measured in kWh/year, is the difference between the actual Primary Energy compared to the Primary Energy required by the building after the retrofit phase.
2. The criterion g_2 *Energy impact* is the percentage of annual reduction of the Primary Energy allowed by the implementation of each measure.
3. The criterion g_3 *Environmental emissions* is the difference between the annual CO_2 emission obtained in actual conditions and after the retrofit phase.
4. The criterion g_4 *Energy class* considers the actual energy class of the building which ranges from A to G, as defined by the European Directive 2010/31/EC, where A is the most energy efficient and G the least efficient (Bottero, Bravi, Dell'Anna, & Mondini, 2018).

The second subset of criteria, from g_5 to g_7, expresses the financial feasibility of the retrofitting measures.

5. In particular, the criterion g_5 *Investment Cost* corresponds to the initial cost for the implementation of each measure and, therefore, to the number of public funds that are spent. The cost of implementation of retrofitting measures is calculated by applying regional price lists for public works or other national price lists.
6. The criterion g_6 *Net Present Value NPV* expresses the financial convenience in terms of the difference between the discounted revenues and costs, according to formula (1).

$$NPV = -C_0 + \sum_{t=1}^{n} \frac{(R_t - C_t)}{(1+r)^t} \quad (1)$$

where: R_t are the revenues at the year t; C_0 is the investment cost; C_t represents the operating cost at the year t; r is the discount rate; n is the numbers of years in the time frame of the analysis. As far as the revenues are considered, they both refer to operating revenues, deriving from energy savings (Bottero, D'Alpaos, & Dell'Anna, 2019).

7. The criterion g_7 *Simple payback period* calculates the recovery time, expressed in years, of the C_0 investment costs by analyzing the incoming and outgoing liquidity flows without the discount factor. The PbP is the length of time an investment reaches the break-even point, where the cash inflows allow earning back the initial cost.

The last criterion g_8 *Constraints* concerns the compatibility of retrofitting measures with the constraints set by regional and landscape plans.

8. This criterion g_8 is assessed by directly examining the Regional Territorial Landscape Plan (RTLP) of the Apulia Region[1]. The buildings considered in the present case study are located in areas with different environmental and historical-cultural characteristics, and they are subjected to 13 different categories of RTLP constraints (Figure 6). For each one of the considered buildings, the number of constraints falling in the RTLP categories is assessed.

[1] D.G.R. no.176, 16.02.2015 and D.Lgs. 42/2004 "Codice dei beni culturali e del paesaggio".

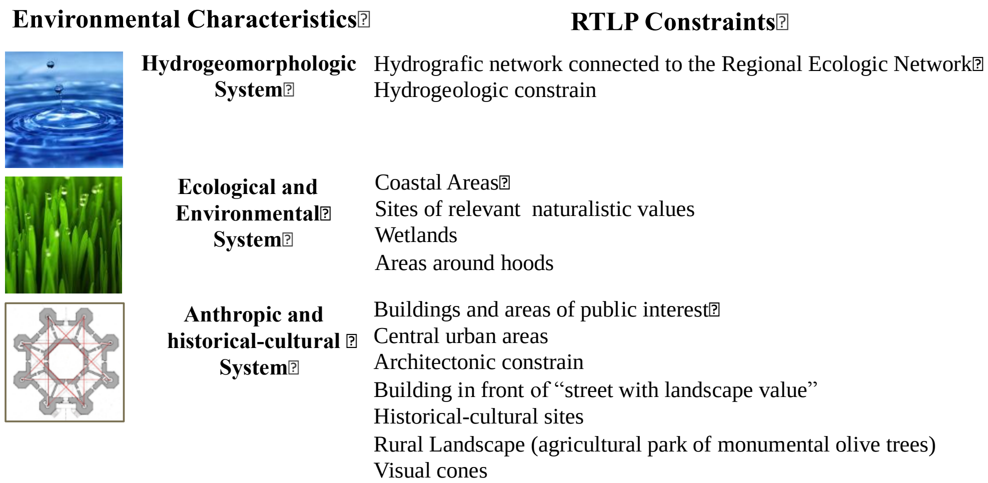

Figure 6: Categories of the PPTR constraints in the areas of the case study

4.3 *Determining the performance table*

The methodologies of energy and financial analysis, as well as the evaluation of territorial and landscape constraints previously described have been applied to assess the performance of the 210 alternative retrofitting actions according to the eight criteria of the model.

The results of the evaluations are reported in the performance table (Table 4) and are the basis for the application of ELECTRE TRI-nC in order to to sort the alternatives into categories.

Table 4: Example of performance table for the retrofitting measures 1-12 of 210

Retrofitting Measures			Criteria							
Action	Building	Type of measure	g_1 Reduction of primary energy	g_2 Energy impact	g_3 Environmental emissions	g_4 Energy class	g_5 Investment cost	g_6 Net Present Value	g_7 Pay-back Period	g_8 Constraints
Name	Name	Name	kWh/year	%/year	ton CO_2/year	ordinal	euros	euros	years	No.
A001	B01	OI	298,951	56.5%	63,595	F	443,149	-28,707	15	3
A002	B01	TE	51,464	9.7%	11,028	F	414,876	-343,522	>25	3
A003	B01	BM	76,318	14.4%	16,174	F	104,568	1,144	14	3
A004	B01	TR	18,012	3.4%	3,676	F	14,463	10,511	8	3
A005	B01	LS	62,863	58.5%	27,232	F	101,105	57,185	9	3
A006	B01	LS	11,840	11.0%	5,129	F	26,170	3,643	12	3
A007	B02	OI	14,320	45.0%	9,963	E	62,495	-4,582	15	3
A008	B02	TE	3,413	10.7%	2,375	E	47,586	-33,779	>25	3
A009	B02	BM	6,852	21.5%	4,767	E	31,635	-3,942	16	3
A010	B02	LS	7,001	55.9%	3,033	E	10,980	6,643	9	3

A011	B02	LS	2,920	53.3%	1,265	E	7,694	-341	15	3
A012	B02	LS	2,054	16.4%	890	E	3,800	1,371	10	3

4.4 Constructing the weights and reference profiles

For the development of the evaluation, a series of interviews with an experts' panel has been carried out in order to:

- validate the structuring of the decision problem with reference to the family of criteria and the proposed discriminating thresholds;
- define the weights of the evaluation criteria;
- define the limiting profiles for the classification of the alternative actions.

More in detail, in order to define the weights of the criteria of the evaluation model, the revised Simos procedure (SRF) (Figueira & Roy, 2002) has been applied within the experts' panel. The interviews were carried out through the set of cards methodology that allows setting the criteria weights and determining their priority, according to experts' preferences.

Figure 7 reports the arrangements of the cards defined by the panelists, whereas Table 5 represents the set of weights resulting from the SRF application. It has to be noticed that two different sets of weights are considered (w^1 and w^2) according to the different values of z defined by the experts' panel (z=7 and z=10, respectively). According to the SRF procedure, z represents the ratio between the most important criterion and the least most important one in the ranking.

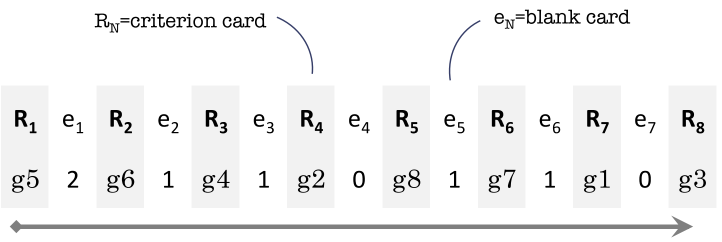

Figure 7: Ranking of cards and number of blank cards defined by the experts' panel (from left to right, from the least to the most important)

Table 5 also reports the discriminating threshold defined with the help of the experts' panel. Following the ELECTRE TRI-nC method, the definitions of discriminating thresholds (indifference and preference threshold) which indicate the indifference threshold q and the strict preference threshold p ($p \geq q$) have been provided. The value for the veto threshold, v, has been attributed to certain criteria to characterize discordance effects. The thresholds have been defined as variable or constant values.

Table 5: Criteria parameters defined by the experts' panel (w: weight; q: indifference threshold; p: preference threshold)

	g1 Reduction of primary energy	g2 Energy impact	g3 Environmental emissions	g4 Energy class	g5 Investment cost	g6 NPV	g7 PbP	g8 Constraints
w^1	18.80	12.20	20.10	9.5	2.90	6.80	16.2	13.5
w^2	19.30	12.10	20.80	9.3	2.10	6.40	16.4	13.6
q^α	0.05	0.05	0.10		0.05	0.05		
q^β							1	1
p^α	0.10	0.15	0.20		0.15	0.15		
p^β							3	2
v^α	0.20		0.30		0.30	0.30		
v^β								
Direction	max	max	max	max	min	max	min	max
Threshold	var	var	var	const	var	var	const	const

Following the methodology, five categories have been defined together with the panel in order to sort the 210 actions to deliver recommendation about the interventions. In particular, the five categories are named excellent (C5), good (C4), moderate (C3), weak (C2) and bad (C1).

For each category some characteristic reference actions were defined by the experts' panel. In this sense, according to the basic idea of ELECTRE TRI-nC, by means of a co-construction process we demanded to the experts to define retrofitting measures representative of certain levels of performances related to the five identified categories (Table 6). Figure 8 shows a graphic representation of the lower and upper limits of the five categories defined by the esperts, where *b5* is the the upper limit of category *B5*, *b42* represents the lower limit of category *B5 and the upper limit of category B4*, b41 is the lower limit of category *B4* and the upper limit of *B3*, so on to *b11* that represent the lower bound of *category B1*.

Table 6: Reference measures of characteristics

B_h	b_{rh}	g1	g2	g3	g4	g5	g6	g7	g8

B1	*b11*	50,000	15	10,000	1	1,100,000	0	26	0
B2	*b21*	100,000	25	20,000	2	1,000,000	50,000	25	1
	b22	150,000	40	30,000	2	750,000	100,000	15	1
B3	*b31*	200,000	50	40,000	2	500,000	200,000	12	2
	b32	250,000	55	50,000	3	400,000	300,000	9	2
B4	*b41*	375,000	60	75,000	3	300,000	400,000	6	3
	b42	500,000	70	100,000	4	200,000	500,000	4	3
B5	*b5*	510,000	71	110,000	4	100,000	510,000	0	4

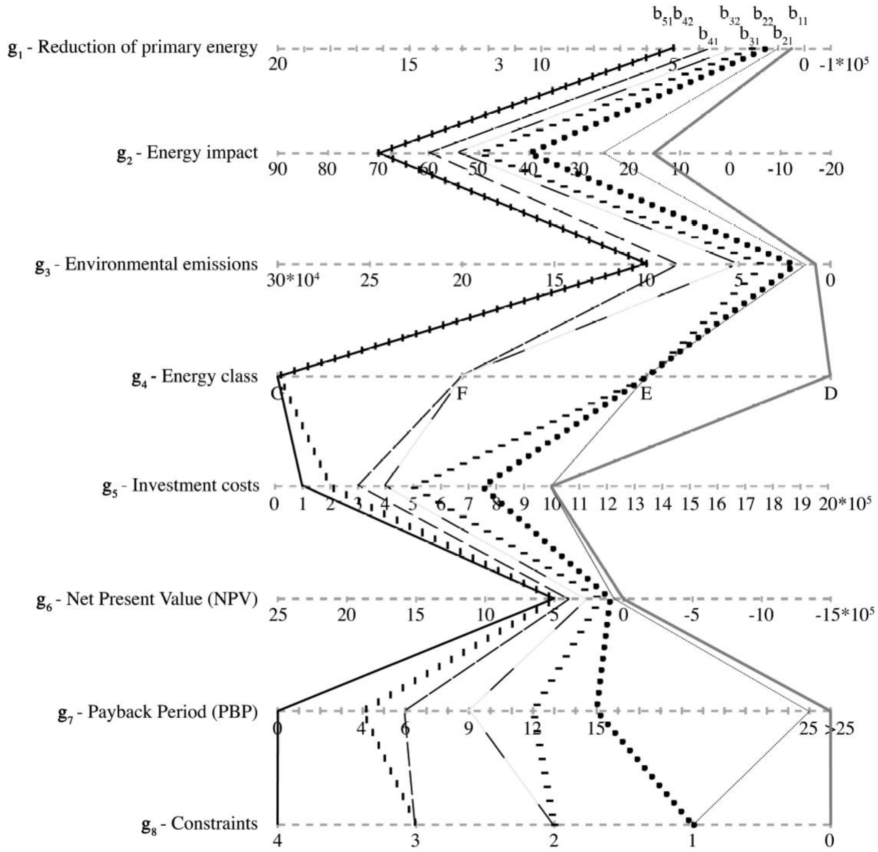

Figure 8: Graphical representation of the reference retrofitting measures

4.5 *Classifying the alternatives*

The ELECTRE TRI-nC method is applied to the case under investigation, by means of the MCDA-ULaval[2] software, using a credibility level λ = 0.65. Computational time in arriving at a solution is instantly, allowing to operate real-time if the decision problem changes. Table 6 and Figure 9 summarizes the results of the application considering the

[2] MCDA-ULaval is a free tool programmed in Java that implements multiple criteria decision analysis algorithms. Supported decision methods are Electre II, III, Tri-B, Tri-C, Tri-rC and Tri-nC (available at: https://cersvr1.fsa.ulaval.ca/mcda-ulaval/?q=en).

two sets of weights w^1 and w^2, whereas a sample of the category assignment to the measures is reported in Table 7.

Table 7: Statistics of the assignment results for the two considered sets of weights w^1 and w^2

Categories	*Configuration w^1*	*Configuration w^2*
<min, max>	#	#
<C1,C1>	46	42
<C1,C2>	20	24
<C1,C3>	1	1
<C2,C2>	82	82
<C2,C3>	-	1
<C3,C3>	45	44
<C3,C4>	1	1
<C4,C4>	11	11
<C5,C5>	4	4

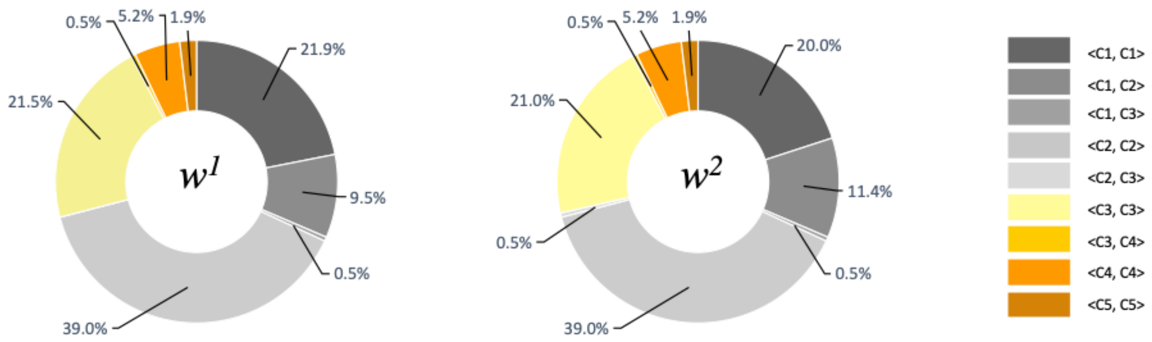

Figure 9: Statistics of the assignment results for the two considered sets of weights w^1 and w^2

Table 8: Assignment of the categories for the set of the weights w^1 and w^2

Category Minimum Maximum	*w^1*	*w^2*
C5 excellent, C5 excellent	67, 96, 132, 136	67, 96, 132, 136
C4 good, C4 good	13, 54, 60, 98, 119, 128, 133, 134, 150, 168, 170	13, 54, 60, 98, 119, 128, 133, 134, 150, 168, 170
C3 moderate, C4 good	122	122
C3 moderate, C3 moderate	1, 5, 18, 25, 30, 38, 39, 55, 56, 68, 70, 71, 74, 82, 86, 87, 94, 101, 102, 103, 105, 107, 113, 114, 120, 124, 125, 129, 130, 137, 138, 140, 142, 143, 158, 188, 189, 191, 198, 199, 201, 207, 208, 209, 210	1, 5, 18, 25, 30, 38, 55, 56, 68, 70, 71, 74, 82, 86, 87, 94, 101, 102, 103, 105, 107, 113, 114, 120, 124, 125, 129, 130, 137, 138, 140, 142, 143, 158, 188, 189, A191, 198, 199, 201, 207, 208, 209, 210
C2 weak, C3 moderate	-	78
C2 weak, C2 weak	3, 7, 14, 15, 19, 20, 21, 26, 28, 31, 32, 33, 40, 41, 46, 47, 49, 50, 53, 57, 58, 59, 61, 62, 63, 66, 69, 72, 73, 75, 76, 77, 78, 80, 81, 84, 85, 88, 89, 91, 92, 97, 99, 106, 108, 109, 110, 111, 116, 121, 123, 131, 135, 139, 145, 146, 147, 148, 151, 152, 153, 156, 157, 159, 162, 165, 166, 167, 169, 171, 172, 177, 178, 179, 184,	3, 7, 14, 15, 19, 20, 21, 26, 28, 31, 32, 33, 39, 40, 41, 46, 47, 49, 50, 53, 57, 58, 59, 61, 62, 63, 66, 69, 72, 73, 75, 76, 77, 80, 81, 84, 85, 88, 89, 91, 92, 97, 99, 106, 108, 109, 110, 111, 116, 121, 123, 131, 135, 139, 145, 146, 147, 148, 151, 152, 153, 156, 157, 159, 162, 165, 166, 167, 169, 171, 172, 177, 178, 179, 184,

	194, 196, 197, 200, 202, 203, 205	194, 196, 197, 200, 202, 203, 205
C1 bad, C3 moderate	154	154
C1 bad, C2 weak	4, 6, 10, 11, 16, 17, 34, 35, 36, 37, 51, 52, 64, 65, 79, 163, 174, 181, 182, 204	4, 6, 9, 10, 11, 16, 17, 24, 34, 35, 36, 37, 51, 52, 64, 65, 79, 118, 163, 174, 175, 181, 182, 204
C1 bad, C1 bad	2, 8, 9, 12, 22 ,23, 24, 27, 29, 42, 43, 44, 45, 48, 83, 90, 93, 95, 100, 104, 112, 115, 117, 118, 126, 127, 141, 144, 149, 155, 160, 161, 164, 173, 175, 176, 180, 183, 185, 186, 187, 190, 192, 193, 195, 206	2, 8, 12, 22, 23, 27, 29, 42, 43, 44, 45, 48, 83, 90, 93, 95, 104, 112, 115, 117, 126, 127, 141, 144, 149, 155, 160, 161, 164, 173, 176, 180, 183, 185, 186, 187, 190, 192, 193, 195, 206

5. Discussion of the results

This section discusses the obtained results on the performances described above. The classification of the alternative measures is examined paying particular attention to the type of retrofitting measures. This section also summarizes the implications of the results on the real decision-making process.

5.1 Assignments Results

As it is possible to see from Table 8 only 4 retrofitting actions are classified as excellent (category <C5,C5>) and 11 as good (category <C4,C4>), representing nearly the 7.15% of the total set of solutions. On the contrary, the majority of the solutions are classified as bad or weak, representing more than the 71% of the set.

It is interesting to notice that the resulting assignments are almost stable. In order to know how the weights may have affected the results, the comparison of the assignments w^1 against w^2 shows that the number of actions remains unchanged for the categories <C1,C3>, <C2,C2>, <C3,C4>, <C4,C4>, and <C5,C5>, whereas just 4 actions are shifted from the <C1,C1> towards the <C1,C2> category.

Paying particular attention to the typology of the retrofitting actions, the analysis of the alternatives classification gives us further points of discussion. The actions related to the opaque envelope insulation (OI) provide the best performances as a very high percentage of 37 measures are classified as excellent (33%) or as good (43%), given the fact that most of them show high values on NPV, a great reduction of energy consumption and CO_2

emissions and are often referred to buildings with presence of landscape or architectural constraints. The upgrade of the HVAC system (HS) also provides satisfactory performances as a relevant percentage (75%) of the actions is classified as moderate category mostly due to a not very significant reduction of energy consumption. It is interesting to notice that the actions related to three typologies, namely BM - Upgrade of building management and automation systems, TE - Upgrade of transparent envelope performances, and TR - Upgrade of thermoregulation system, show almost the same classification as the category assigned to a significant number of them (from 28% to 36%) is good-excellent or moderate, whereas other actions are classified as bad-weak due to both a low reduction of primary energy and a low landscape or architectural quality. Moreover, it is worth to mention that the measures classified as bad mostly pertain to the upgrade of lighting system (LS), installation of PV system (PS), and installation of solar thermal system (SS), because, although they mostly require a moderate investment cost, the corresponding reduction in energy consumption is quite low.

5.2 Analyzing the implications of the evaluation

Once the final results were obtained, an interview was organized with the experts' panel involved in this study. The purpose of the interview is to understand if the results obtained were consistent with the panel opinion and background.

Firstly, the alternatives in C4 and C5 categories, good and excellent, were presented to the experts' panel who were convinced about their good classification (Bertolini, D'Alpaos, & Moretto, 2018). We thus showed them the specific typologies of buildings classified as good or excellent under the opaque insulation intervention, that were mostly related to school buildings and swimming pools. The experts' panel agreed with classification and they stated that school buildings are characterized by high consumption of thermal energy, so an improvement in insulation allows achieving excellent results in terms of energy savings. A high thermal set point characterizes the gyms compared to other uses, so a reduction in heat loss reduces energy expenditure. We then moved to the analysis of the interventions falling into the worst categories (i.e. C1-bad and C2-weak). In particular, the experts' panel agreed that most of the interventions related to the lighting systems were classified as bad or weak.

As far as the evaluation model is considered, the experts' panel found it very simple to interpret the results obtained from the analysis. The subdivision of alternatives into categories is, in their opinion, very effective and clear in the communication of results. Weighing criteria using the deck of cards method has proved to be very easy for the experts' panel to do. Moreover, the experts' panel did not find significant difficulties in defining the profiles of the categories for the different criteria taken into consideration in the analysis. The definition of the profiles of the most technical criteria was straightforward, while some difficulties arose in the definition of the profiles of the qualitative criteria.

6. Conclusions

Following the new perspectives of the United Nations, SDG 11 provides that all countries must contribute to achieving environmental sustainability in urban areas based on their capacity by 2030. In this perspective, the requalification of existing building stock represents a great potential to reach the goal set. However, to stimulate the buildings' retrofit, new local policies supported by decision-aid tools that address the problem considering the economic, social and environmental dimensions are needed (Monfared, Ghasemi, Loni, & Marzband, 2019; Pourakbari-Kasmaei, Lehtonen, Fotuhi-Firuzabad, Marzband, & Mantovani, 2019).

In response to the public administrations requirement of allocating public financial resources on the basis of principles of environmental sustainability, energy-saving, and protection of historical-architectural and landscape assets, we proposed a Multiple Criteria Decision Aiding model to select the best energy retrofitting measures of public buildings located in contexts with high architectural, landscape and environmental quality.

The multiple criteria model considered the development of the ELECTRE TRI-nC method and included three types of criteria, namely energy efficiency, financial feasibility, and architectural/landscape constraints. The evaluation was applied to a real case study in Southern Italy, consisting of a set of 210 energy retrofitting actions that were proposed from the results of the energy audit of 36 public buildings, and besides an experts' panel was consulted for the structuring and application of the model. The use of ELECTRE TRI-nC method allowed sorting the retrofitting measures into categories and selecting those that are wortly of being financed as a priority, also taking into account the constraints to protect the architectural, landscape and environmental assets.

The results that have been obtained so far show that a large part of the retrofitting measures was classified as bad or weak, whereas the best ones belonged to the opaque envelope insulation. On the contrary, the worst ones were of the upgrade of lighting system type as well as installation of a solar thermal or photovoltaic system. The interaction between the analysts and the panel made it possible to understand that the results obtained were consistent with the opinion of the experts who also agreed on the importance of considering the profiles of the categories and suggested that further research should be carried out in order to develop user-friendly protocols for the definition of the profiles. More generally, the application proved that ELECTRE TRI-nC models have different appealing features in the area of investment decisions.

Firstly, these models allow the DMs to describe the evaluation classes using multiple reference profiles instead of only one, thus allowing major freedom in the development of the approach.

Secondly, the method provides the final results in an interval form, according to the uncertainty and ambiguity that usually describes real-world problems in the context of projects. Previous research (Doumpos & Figueira, 2019) also proved that ELECTRE TRI-nC method provides more accuracy in the classification in comparison with other multi-criteria classification methods, such as UTADIS which uses mathematical programming approach to infer an additive value function optimally. Another study (Costa, Govindan, & Figueira, 2018) compares ELECTRE TRI-nC with the probabilistic CPP-TRI method (Sant'Anna, Costa, & Pereira, 2015) and concludes that the possibility of ELECTRE TRI-nC method to consider the imperfect knowledge of the performance leads to better results.

Apart from the specific need of appliance of the present stud, the results have also important implications for other domains, thus contributing to the decision of ELECTRE-type methods for the decision of effective procedures of decision aiding.

It has to be noticed that the application illustrated in the present paper refers to preliminary experimentation of the ELECTRE TRI-nC method for the decision problem under investigation and thus, several areas of future research can be outlined. Future work will thus be developed for the implementation of the method, considering other configurations of the experts' panel (Bottero, Ferretti, Figueira, Greco, & Roy, 2015, 2018) and different levels for the discrimination thresholds (Figueira & Roy, 2002).

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