A multi-criteria application to select energy retrofit measures at the building and district scale

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Abstract

The rapid growth of urbanization stresses the necessity of new sustainable paradigms for transition strategies toward energy efficient cities. Particularly, the building sector plays a fundamental role in driving urban energy consumption and GHG emission reduction.

Improving the energy efficiency of existing buildings has a great potential, however selecting among the multiple available retrofit solutions may result difficult for a decision maker.

This work is an application of the PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) method in order to provide a guideline for ranking different alternatives of building retrofitting at the building and district level. To this end, the case study of Torino has been selected for outranking five different retrofit alternatives. First, the retrofit alternatives were applied to a district and second, the same procedure was tested at the building level. The double scale approach provides guidelines to both municipalities and citizens. The proposed model supports building and district designers, energy planners and decision makers for ranking complex design energy retrofit options.

Keywords: PROMETHEE, District and Building Scale, Energy Retrofitting

Highlights:

- The PROMETHEE method is applied to outrank building retrofit alternatives
- Two case studies at the different scales of urban and building are proposed
- The study highlights the importance of citizen preferences in decision-making

1 Introduction

Most of the European building stock pre-dates the energy regulation and is responsible of 40% of energy consumption, with a potential of 90% emission reduction up to 2050 [1]. Lots of efforts are nowadays devoted to the definition of proper retrofitting strategies in the built environment sector. Wide ranges of solutions are available in order to reduce the energy consumption of a building [2] involving both the envelope and the energy system. Nevertheless, for either a citizen [3] or a municipality may be difficult select a proper retrofit option. When a decision needs to be taken, a set of sustainable aspects needs to be considered [4]. As discussed by [5], the energy planning of local systems is a very complex task and may be supported by Multi Criteria Analysis (MCA). Principally, it represents a method that can support decision making when more than one criterion is involved [6]. MCA translates complex problems into simpler ones and it has been widely applied to the energy planning field [7,8]. In the energy planning sector, MCA methods are classified in literature into four principal classes [9]: (i) Value measurement models (e.g., AHP, MAUT) (ii) Goal, aspiration and reference level models (e.g., TOPSIS) (iii) Outranking models (e.g., ELECTRE, PROMETHEE) (iv) Combination of methods.

Depending on the problem definition context, the appropriate MCA method should be selected. In particular, outranking methods are suitable for territorial analysis [10] Examples of outranking methods are ELECTRE, PROMETHEE and ORESTRE. More specific information on outranking decisions can be found in [11–13].

This paper is the continuous of the research conducted by [14] in which the PROMETHEE method has been selected for outranking five building retrofit alternatives at the district level. Starting from the previous evaluations, in this paper the building scale evaluation is added in order to highlight the different perspective between public and private sectors. In fact, at the building scale, the decision maker is a single citizen assumed as the owner of the building and the goal is to select the most appropriate retrofit intervention for its own building [15]. At district level, on the contrary, the municipality is the decision maker and the goal is to outrank the proposed alternatives for buildings refurbishment that allows to achieve 20% energy saving.

Section 2 describes the PROMETHEE method and its phases that are consequently applied to the case studies. Section 3 presents and discusses the results of the two case studies while Section 4 summarizes the concluding remarks and future development.

2 Material and methodology: case study description and PROMETHEE methodology

The PROMETHEE method, developed by Brans et al. [16], has been chosen in this study due to its simplicity and because it has been used broadly in the field of energy planning and its applications, such as [17]. Therefore, the PROMETHEE method fits the purpose of this paper and it is used to outrank the proposed energy retrofit alternatives. Moreover, the presented methodology could be applicable in other similar urban areas. This section introduces the main features of the methodology and then illustrates the selected case studies.

2.1 Method

The PROMETHEE method is based on the pairwise comparison that is able to rank a restricted number of alternatives characterized by conflicting criteria [18]. Criteria weights and decision-maker's preference function are the two-main necessary information in the implementation of this method. In this paper, the PROMETHEE application follows the instructions provided in [19], which is summarized in Figure 1.

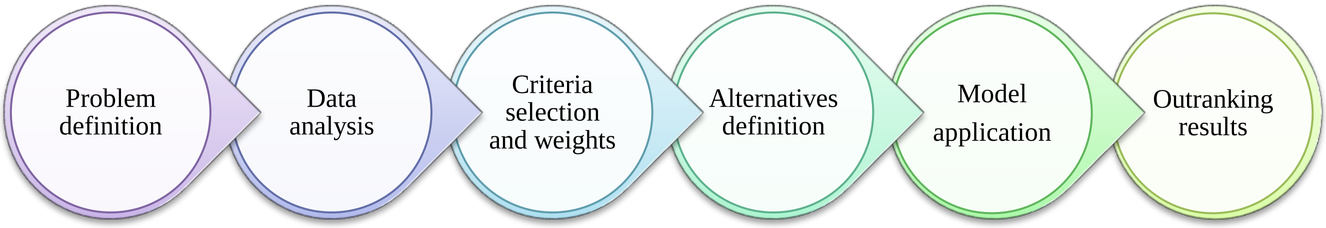


Figure 1. Conceptual framework of the methodology

The first step consists in defining problems and objectives of the analysis in the given planning context. Once the problem is clearly defined, the data collection and analysis process can start. In case of a large database (e.g., urban context), Geographic Information Systems (GIS) tools can support the data collection process [20]. Taking into account the data availability, the previous literature [21] and the problem, the selection of a set of non-redundant criteria [22] and their relative weights represents the next step in the procedure. Afterward, a group of several stakeholders needs to be involved to select the final set of criteria based on the stakeholders' preferences and knowledge. At this point, the stakeholders assign a weight to each criterion. Since results are strongly affected by the weights assignment, this step is particularly important. Furthermore, the alternatives to be outranked should be defined by the analysts combining different retrofit measures involving the buildings envelope or heating system. This step can also be performed with a participative approach. Finally, the PROMETHEE method outranks the retrofitting alternatives. Using this method, the alternatives are pairwise compared based on the ϕ value. The ϕ is an indicator used to select the best alternatives. It is calculated as the difference between the positive and negative outranking flows. The best alternatives are therefore the ones characterized by higher ϕ values.

2.2 Problem definition

This paper simulates the specific case where a Municipality would like to invest part of his budget to finance the energy retrofit of the residential stock in order to improve the life quality of its inhabitants. This paper applies the MCA method to: (i) support the municipality deciding which energy retrofit alternative to promote (district scale analysis) and at the same time (ii) understand if the identified "best" alternative at the district scale may represent also the "best" option for a citizen (building scale analysis).

In this analysis it is assumed that the Municipality fixes its energy savings target to 20% compared to the actual performance. That the Municipality can invest a maximum of 17 M€ to finance the building energy retrofit. In this hypothetical situation, the budget of 17 M€ is intended as an economic incentive to citizens to finance up to 60% of the capital cost of the retrofit alternative. In this vision, the citizens will cover only 40% of the initial capital cost. This particular situation has been taken by authors in order to test a possible new policy in alternatives to the current tax detraction over 10 years.

The problem definition is therefore:

- For the district scale (Municipality perspective): "Which energy retrofit alternatives and strategies are best applied to generate both economic and socio-environmental benefits for the local community?"
- For the building scale (Citizen perspective): "Which energy retrofit alternative is best applied to generate both economic and socio-environmental benefits for my building?"

The next sections of the paper follow the methodological framework presented in Figure 1 for the two scale analyses.

2.3 Data analysis

The case studies area involves residential buildings sited in the "District 3" of the city of Torino, Italy. The city of Torino is characterized by 8 districts composed by roughly 40,000 residential buildings distributed into 3839 census sections. District "3" has 432 census sections, 5585 residential buildings that occupy a net volume of 23.15 Mm^3 with 125, 443 inhabitants (2017) [23]. As mentioned before, this study applied the methodology on two different scales: building and district level. Regarding the district scale, a total of 198 sample buildings from which space heating energy consumption data were available were considered. Among these buildings, the prevailing building type was selected for further analysis at the building scale. Figure 2 shows the case study area that has been characterized in terms of geometry and energy thermal consumption in the previous work of [24]. The building sample volumes range from 3000 to 30,000 m^3. All the buildings are assumed to be heated by a gas boiler (η=0.8). The considered archetypes in this research refers to the ones of the European Project TABULA [25] , from which it is possible to derive all the buildings characteristics.

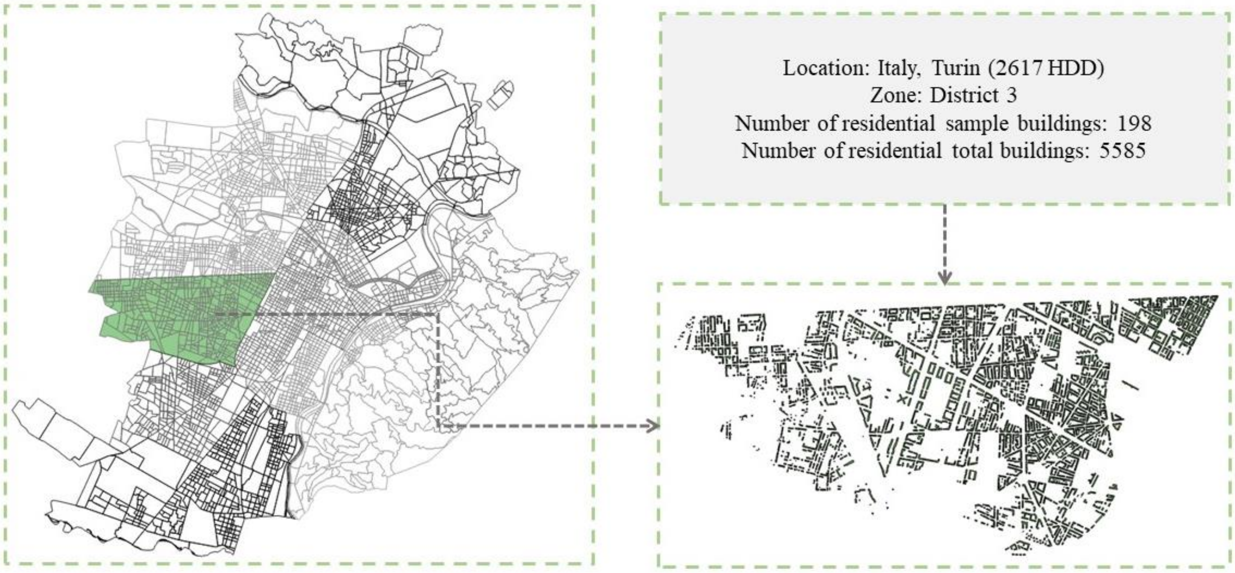


Figure 2. Case study district in Torino in which the 198 sample buildings are sited

The building samples selected for this specific case study have been classified in 5 building categories as summarized in Table 1. Description of sample buildings categories The great majority of buildings belong to the category "Building Type 1" that, for this reason, has been selected as Reference Building Type for the building scale analysis.

Table 1. Description of sample buildings categories.

Building category	Description	Number of sample buildings	Actual space heating performance (kWh/m^{2}y) [24]
Building Type 1	Multi-family built before 1980	132	136,5
Building Type 2	Single-family built before 1980	50	332,5
Building Type 3	Multi-family built from1981 to 2005	8	80,5
Building Type 4	Single-family built from 1981 to 2005	6	126
Building Type 5	Multi-family built after 2006	2	35

2.4 Criteria selection

In this section, the process for selecting the criteria and the relative weights is described. For both the case studies, criteria, alternatives and weights were defined through a focus group constituted by three experts: an urban expert, a building expert and an energy expert. For this analysis, the authors undertake the role of decision-makers since the aim of the work is academic. As a consequence of the focus group discussion the criteria for the two different cases have been selected. Criteria are divided into quantitative (economic) and qualitative (socio-environmental). For assessing qualitative criteria, specific ordinal scales have been defined. The calculation period for evaluating some of the quantitative criteria has been assumed as 30 years.

2.4.1 District scale criteria

For the district scale analysis, eight criteria have been defined by the focus group. Even if the decision should be taken by the Municipality, some criteria (i.e. replacement cost and maintenance cost) have been defined in order to take care of citizen desires.
Quantitative criteria are represented by:

- Investment Cost C1 (M€): the capital cost of alternatives to be financed by the Municipality. The values of investment cost associated to each alternative has been evaluated by referring to the Italian regional price list database [26];
- Replacement Cost C2 (M€): investment costs to be repaid by the citizen at the present time to replace an alternative according to its technical life (when the calculation period is longer than the technical life of the alternative). These values are the same as in C1, discounted at present level with a discount rate assumed equal to 3.5% (present net value) [27];
- Maintenance Cost C3 (M€): fixed costs to be sustained by citizens during the technical life of the alternatives (evaluated with a discount rate assumed equal to 3.5% [27]). Operation and Maintenance (O&M) costs have been considered 0% of investment costs for envelope components and 2% of investment costs for energy system components.;
- Tax detraction C4 (M€): the amount of money that the Municipality is not giving to citizen for tax detraction over 10 years (in this paper the tax detraction option has been substituted by covering a 60% capital investment);
- Internal comfort C5: related to the attended retrofit results in terms of comfort and to the efficiency of technologies. This criterion has been considered proportional to the number of retrofitted buildings.

Qualitative criteria are instead divided into:

- Reliability C6: intended as the presumed satisfaction with the new internal thermal environment at the district level. The relative ordinal scale can be observed in Table 2;
- Built environment (BE) value C7: level of beautification of the built environment. The relative ordinal scale can be observed in Table 2;Social image and awareness C8: how the choice of the alternative rises the citizens' awareness to the environmental benefits and their pro-active behaviour. The relative ordinal scale can be observed in Table 2.

Table 2. Ordinal scales of qualitative criteria.

		Ordinal scale value				
Criterion		1	2	3	4	5
Reliability C6	Probability of success	Failure	Low	Medium	High	Success
	Description	Efficiency of the technology lower than 80% and probability of	Efficiency of the technology lower than 80% or	Efficiency of the technology higher than 80% or	Efficiency of the technology higher than 90% and probability of	Efficiency of the technology equal to 100% and probability of success of

		success of the measure lower than 70%	probability of success of the measure lower than 70%	probability of success of the measure higher than 80%	success of the measure higher than 80%	the measure higher than 90%
Built Environment (BE) C7	Acceptability	Unacceptable	Low	Medium	High	Very high
	Description	Degraded BE	Worsened BE	The BE does not change	Beautification of the BE	Consistent beautification of the BE
Social image and awareness C8	Acceptability	Unacceptable	Low	Medium	High	Very high
	Description	Alternative not in the cultural tradition of the area and citizen not aware about the benefits	Alternative not diffused in the area and citizen are scarcely aware about the benefits	Alternative normally adopted in the area and the related benefits are mostly known	Alternative normally adopted in the area and the related benefits are well known	Alternative widely adopted in the area and the related benefits are well known

2.4.2 Building scale criteria

In order to define the evaluation criteria at the building scale, the focus group identified six criteria. As can be seen below, the criteria are slightly different from the ones of the district scale since the citizens had different preferences and objectives compared to local community. In particular, differently to the district case, the criterion related to comfort (Improvement of Internal Thermal Comfort) is qualitative assumed dependent to the number of variables that are actually positively affected by the retrofit options.

Quantitative criteria are represented by:

- Investment Cost C1 (M€): this criterion is described in the previous section (2.4.1). The values of investment cost associated to each alternative has been evaluated by referring to the Italian regional price list database [26];
- Energy bill savings C2 (k€): amount of money saved thanks to energy consumption reduction after retrofitting. These values are estimated by multiplying the energy savings amount per the current Italian energy prices for gas and electricity provided by the Italian Regulatory Authority for Electricity Gas and Water [28];
- Maintenance and Replacement Cost C3 (M€): these costs are described separately in the previous section (2.4.1) as C2 and C3 criteria. O&M costs have been considered 0% of investment costs for envelope components and 2% of investment costs for energy system components.

Qualitative criteria are instead divided into:

- Reliability C4: intended as the presumed satisfaction of the owners to improve the quality level of their building with the energy retrofit. The ordinal scale is the same as the district case, but the failure level includes one more option: the case in which any retrofit action is undertaken;

- Improvement of Internal Thermal Comfort C5: related to the attended retrofit results in terms of comfort. This criterion has been considered proportional to the number of parameters that will vary with the retrofit measures. The considered parameters are the air temperature, the relative humidity, the mean radiant temperature and the internal air speed. The ordinal scale of the criteria can be observed in Table 3;
- Social image and awareness C6: it doesn't change from the one of the previous section (2.4.1), C8 criterion. The ordinal scale is the same as the district case, but the unacceptable level includes the case with no retrofit action.

Table 3. Ordinal scale of the qualitative criterion C5.

		Ordinal scale value				
Criterion		1	2	3	4	5
Improvement of Internal Thermal Comfort C5	Probability of success	Failure	Low	Medium	High	Extremely high
	Description	No improvement	The package improves the control of one of the parameters related to the comfort	The package improves the control of two of the parameters related to the comfort	The package improves the control of three of the parameters related to the comfort	The package improves the control of four of the parameters related to the comfort

2.5 Definition of alternatives

To each Building Type, some retrofit measures (that define the alternatives to be outranked) are defined. Five measures have been taken into account and combined in different ways. The measures are devoted to improve different parts of the buildings:

- Envelope retrofit: there are two insulation measures, Package 1 for multi-family (allowing 70% energy savings for pre-'80s buildings and 50% for post –'80s) and Package 2 for single-family (allowing 80% energy savings for pre-'80s buildings and 50% for post –'80s);
- Control system: installation of thermostatic valves;
- Heating system: existing boilers substitution with heat pumps;
- Indoor air quality: installation of mechanical ventilation;
- Renewable energy sources: installation of PV panels.

For the Municipality, the energy efficiency measures have been combined and spread on a different number of buildings in order to match the 20% energy savings target while, for the single buildings, just the measures combination is considered. A total of five alternatives, resulting as combination of measures, are taken into account. At the district scale, the alternatives involve a minimum number of 57 buildings to a maximum of 113 where the measures are all combined into separate buildings while, at the building scale, they are all combined on a single building. Furthermore, at the building scale the alternative "absence of energy retrofit measures" is considered. For the building scale application, the energy analysis refers to consumption database and statistical evaluation of the energy improvement. The combination of measures is summarized in Table 4.

Table 4. Alternatives definition.

Alternatives name	Measures combination	District scale buildings	Building scale buildings
Alternative 1 - A1	Envelope retrofit	Envelope retrofit applied to 57 buildings (28 of Type 1, 15 of Type 2, 8 of Type 3 and 6 of Type 4)	Applied to Type 1
Alternative 2 – A2	Envelope retrofit plus control system	Envelope retrofit applied to 52 buildings (24 of Type 1, 14 of Type 2, 8 of Type 3 and 6 of Type 4) and thermostatic valves applied to 54 buildings	Applied to Type 1
Alternative 3 – A3	Envelope retrofit plus control system plus heating system	Envelope retrofit applied to 44 buildings (19 of Type 1, 15 of Type 2, 4 of Type 3 and 6 of Type 4) and thermostatic valves applied to 46 buildings and heat pumps installed (COP = 2.5) into 23 building (19 Type 1 and 4 Type 3)	Applied to Type 1
Alternative 4 – A4	Envelope retrofit plus indoor air quality	Envelope retrofit applied to 38 buildings (18 of Type 1, 14 of Type 2, 4 of Type 3 and 6 of Type 4) and mechanical ventilation installed into 44 buildings	Applied to Type 1
Alternative 5 – A5	Heating system plus renewable energy sources	Heat pumps and PV panels installed into 66 buildings (32 Type 1, 18 Type 2, 8 Type 3, 6 Type 4 and 2 Type 5)	Applied to Type 1
Alternative 6– A6	Absence of energy retrofit measures	Not Applied	Applied to Type 1

Once the alternatives have been defined, for applying the PROMETHEE method, the so-called Performance Matrix needs to be defined. In this matrix, besides the criteria values, the model parameters are specified. The required parameters for each criterion are the indifference (q) threshold, the preference (p) threshold and the weight (w). The indifference (q) of each criterion is set equal to the minimum difference among the alternative values for the criterion. The preference value (p) is instead defined as double of indifference. The "Equal weights method", where the weights of criteria are evaluated as "$w_i=1/n$, $i=1,2,\ldots,n$" has been employed (n is the number of criteria), in the "Baseline" application [21],. The reason of this decision was to compare the alternatives with the same weights to further understand the influence of stakeholders opinion. The Performance Matrix of the district scale analysis is summarized in Table 5 while the one of the building scale is shown in Table 6. All the quantitative presented values have been evaluated by referring to 2.4.1 and 2.4.2, while the qualitative ones emerged from a focus group with the above-mentioned experts.

Table 5. Performance Matrix of the district scale analysis.

		Models parameter			Alternatives				
		w	p	q	A1	A2	A3	A4	A5
Economic Criteria	C1	0.125	0.6	0.3	8.1	7.4	7.1	10.1	3.37
	C2	0.125	0.14	0.07	1.8	2.5	2.8	3.0	1.73
	C3	0.125	0.2	0.1	3.0	2.7	2.6	3.7	1.24
	C4	0.125	0.2	0.1	3.3	3.1	2.6	2.5	0.3
Socio-environmental Criteria	C5	0.125	25	7	57	106	113	84	66
	C6	0.125	-	-	3	4	5	2	2
	C7	0.125	-	-	5	4	3	2	1
	C8	0.125	-	-	4	5	2	1	3

Table 6. Performance Matrix of the building scale analysis.

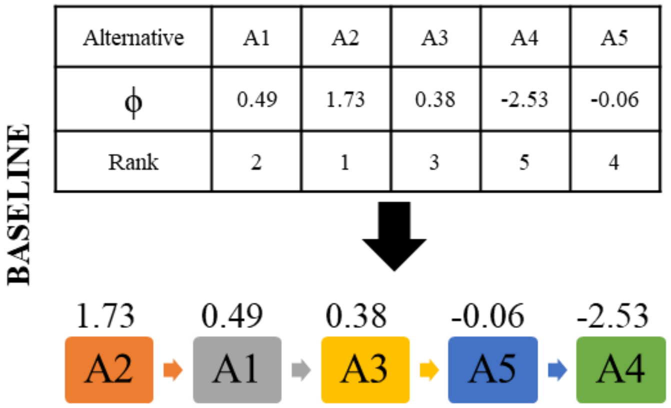
		Models parameter			Alternatives					
		w	p	q	A1	A2	A3	A4	A5	A6
Economic Criteria	C1	0.17	0.02	0.01	0.35	0.36	0.46	0.12	0.65	0.00
	C2	0.17	5.2	2.6	26.00	28.60	34.84	31.72	23.40	0.00
	C3	0.17	1.36	0.68	5.95	6.63	10.03	11.05	3.52	0.00
Socio-environmental Criteria	C5	0.17	2	1	3.00	4.00	5.00	3.00	2.00	1.00
	C6	0.17	1	0.5	2.00	3.00	3.00	5.00	1.00	1.00
	C7	0.17	2	1	2.00	3.00	3.00	2.00	5.00	1.00

3 Results and discussion

In this section, the results for the district and building scales application are presented. Furthermore, a sensitivity analysis is proposed by changing different weights and threshold values with respect to the Baseline alternative, according to stakeholders' opinion. Their opinion and preferences are explained in the following sections. The "Rank-order weights method" [21], where criteria weigh takes into account the relative importance among criteria as "$w_1 \geq w_2 \geq \ldots \geq w_n \geq 0$, $\Sigma w_i = 1$", has been adopted for the sensitivity analysis.

3.1 District scale application

This section summarizes the results at the district scale from the study conducted by [19] with aim at comparing them with the building scale. The PROMETHEE method has been applied to the district case study, as a baseline model, providing the ϕ ranking (**Figure 3**).



Alternative	A1	A2	A3	A4	A5
ϕ	0.49	1.73	0.38	-2.53	-0.06
Rank	2	1	3	5	4

Figure 3: Baseline model.

Figure 3 shows that the highest ϕ value belongs to A2 Alternative, which represent the best alternative. A1 and A3 are characterized by the similar ϕ Values that are considerably lower than A2. Finally, A5 and A4 with the lowest values are the worst alternatives prospectively [19].
In the present study, the robustness of the model was tested by the sensitivity analysis, changing different weights and threshold values with respect to the Baseline alternative (**Table 7**). Two “changes” are proposed in this application, however, for further “changes” the reader can refer to [19].

Table 7. Sensitivity analysis changes.

Baseline		C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8
		Investment Cost	Replacement Cost	Maintenance Cost	Tax Detraction	Internal Comfort	Reliability	Built Environment	Social image
		-	-	-	+	+	+	+	+
Change 1 (baseline +new weights)	w	0.17	0.11	0.11	0.11	0.10	0.10	0.15	0.15
	p	0.60	0.14	0.20	0.2	25.00	2.00	2.00	2.00
	q	0.30	0.07	0.10	0.10	7.00	2.00	2.00	2.00
Change 2 (Baseline + new socio environmental weights)	w	0.17	0.11	0.11	0.11	0.15	0.15	0.10	0.10
	p	0.60	0.14	0.20	0.20	25.00	2.00	2.00	2.00
	q	0.30	0.07	0.10	0.10	7.00	2.00	2.00	2.00

Comparing to the Baseline model, “Change 1” proposes new weights that have been indicated through a structured focus group, however the sums of the economic and socio-environmental criteria weights have remained constant. They are equal to 50% in any cases. A higher weight has been assigned to the Investment Cost criterion due to its importance for the municipality. In the “Change 2” the socio-environmental weights have been changed since it was asked over the focus group. Table 7 shows the proposed weights and thresholds of the district case study.

Results show that the A2 is always in the first rank. In this alternative the costs are acceptable, and simultaneously, the environmental impact is low. Additionally, A2 consist in coating + thermostatic valves actions, which is a well-recognized retrofitting package solution in the market. On the other hand, A4 (i.e., coating + mechanical ventilation) is always a worst scenario due the high costly technologies and very low socio-environmental performances (Figure 4).

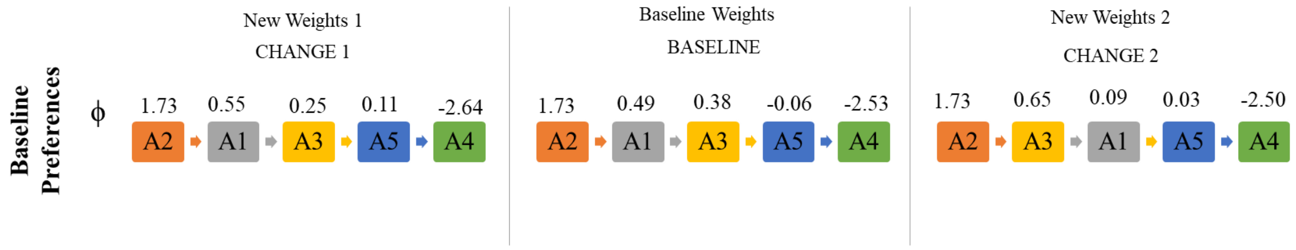


Figure 4. Results of baseline model and two changes.

As it is shown in Figure 4, “Baseline” and “Change 1” are characterized by the same alternatives outranking. These two scenarios were arranged by:

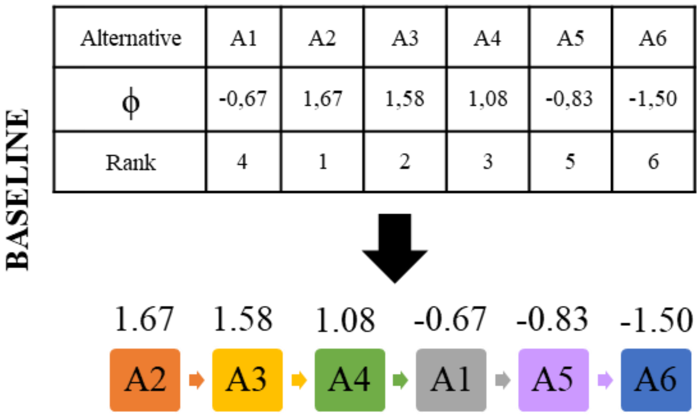
- A2 (coating + thermostatic valves): it allows raising a significant comfort improvement and globally it has the best performances;
- A1 (coating): best performances concerning the built environment and the social image;
- A3 (coating + thermostatic valves + heat pumps): lower costs and higher comfort improvements;
- A5 (PV panels + heat pumps): energy reduction by the lowest price compared to all the other options, worst socio-environmental performances;
- A4 (coating + mechanical ventilation): the investment cost is quite high and it is characterized by a very low socio-environmental performance.

Regarding “Change 2”, Alternative A3 was preferred with respect to A1 since the weight of both Internal Comfort and Reliability of A3 are considerably higher compared to A1.

3.2 Building scale application

This paragraph summarizes the results of the building scale application. The selected building belongs to the Type 1 (see Table 1), which is a multi-family building built during 1918-1980. The shape factor (Surface/Volume ratio) value is 0.32 and his volume is 5 019 m^3.

The PROMETHEE method has been applied to this building and the ϕ ranking is showed in the following Figure 5.



Alternative	A1	A2	A3	A4	A5	A6
ϕ	-0,67	1,67	1,58	1,08	-0,83	-1,50
Rank	4	1	2	3	5	6

Figure 6. Baseline model of the building scale application.

The best Alternative is the A2 which has the higher ϕ value but the second Alternative, A3, has a comparable ϕ. The A4 Alternative has a better position than in the district scale application. The lowest values are associated to the Alternative A1, A5 and A6. From the results, it is evident that there are benefits if an energy retrofit is realized since the alternative A6 is the last alternative in the outranking.

A sensitivity analysis, presented in Table 8, is performed to test the robustness of the model with respect to the Baseline Alternative. The new Alternatives are characterized by different weights.

Table 8. Sensitivity analysis changes.

Baseline		C_1	C_2	C_3	C_4	C_5	C_6
		Economic			Socio-environmental		
		Investment Cost	Save Energy	Maintenance and replacement costs	Reliability	Internal Comfort	Social image
		-	+	-	+	+	+
Change 1	w	0.25	0.125	0.125	0.19	0.19	0.12
Change 2	w	0.25	0.125	0.125	0.16	0.16	0.19

The new weights were defined by the focus group. The sum of the economic and socio-environmental criteria weights was maintained constant and equal to 0.5. In “Change 1” and “Change 2” a higher weight has been assigned to the Investment Cost criterion due to its importance for the citizens. The socio-environmental criteria weights vary. A little weight variation has been proposed to the more technical criteria (Reliability and Internal Comfort) in “Change 1” and to the more social oriented criterion in “Change 2”.

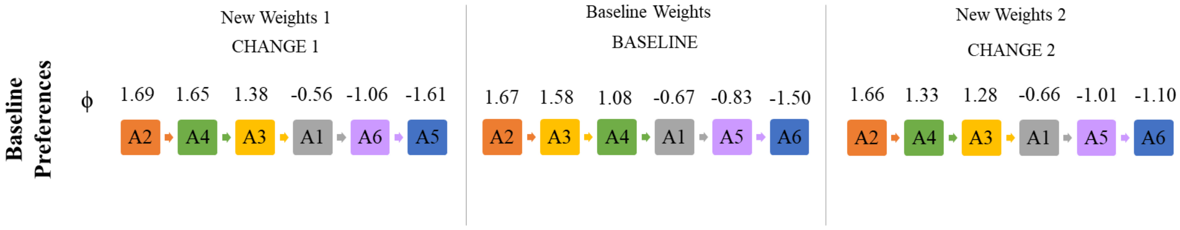


Figure 7. Results of baseline model and two changes of the building scale application.

The results show that the best Alternative is always A2 because is the more suitable with respect to the economic criteria. The second Alternative is A4 for the “Change 1” and “Change 2” because it has lower cost of investment and the weight of this criterion is higher. Furthermore, the ϕ of the Alternative A4 in “Change 1” is close to the first Alternative A2. The worst Alternative is always the A6 except that in “Change 1” where the points of strength of the Alternative A5 are less evident for the new weights.

4 Conclusion and future development

This work intended to provide an academic exercise of MCA application to support the definition of energy retrofit choices. This exercise has been developed by the authors in the role of decision-makers.

The present study presented an application of the PROMETHEE multi criteria method to outrank the different building energy retrofit alternatives at both the building and district levels, considering the citizen and municipality perspective respectively. The study shows that the proposed methodology is applicable at different scales and may help decision-making in selecting among several alternatives. Particularly, the importance of citizens’ preferences was emphasized by introducing specific socio-environmental qualitative criteria. The “non-action” alternative was also proposed. The results showed that the best decision for the public administrative is the same as for citizens. The fact encourages the public administrative to make appropriate policies in this regard and increase the incentives for that action (i.e., coating and thermostat valves). Indeed, in both building and district level, the installation of thermostatic valves coupled with envelope improvement was the best alternative while A4 (PV panels and heat pumps) and A5 (envelope plus mechanical ventilation) were always the worst scenarios, even in the sensitivity analyses.

The result of the paper shows that MCA methods are applicable at different scale and are useful when many options, characterized by competitive qualitative and quantitative criteria, are available. The sensitivity analysis demonstrated that the proposed model is robust and therefore, it is extendible to different European cites.

One of the limitations of this study regards thresholds changing, which were not taken into account in the presented method. The time-consuming approach on data collection and analysis was another very challenging part of the study at district level.

For a possible future development, the following modifications are suggested:

- Increasing the number of criteria for both the building and district levels;
- Applying the model to different case studies in order to validate and test the robustness of the model;
- Improving the evaluation of energy retrofit options;
- Increasing the number of stakeholders involved in the focus group.

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