Real Estate Performance Assessment for Sustainable Refurbishment

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Abstract

The European construction sector is characterized by a great amount of low performances building assets, researchers proved that simply improving the insulation of existing buildings with interventions of refurbishment does not give assurance on actual improvement of buildings sustainability. The aim of the research is to give the interested stakeholder a method that can be used as a certification procedure of buildings condition and in order to choose among different project alternatives to get the most sustainable solution in terms of economy, environment and society. This method investigates mainly two aspects of existing buildings: the building residual performance and the refurbishment potential in terms of sustainability gains. Consequently, the output of this method consists of two indexes: one related to the actual performance and the other to the refurbishment prospective. The first one is assessed considering all the aspects of the existent building, for instance: components service life, degradation, availability of mandatory documents, operational consumptions, etc.. On the other hand, the second index starts from the discovered criticalities and rises with project alternatives able to solve them. These two indexes are developed, starting from existing protocols and software, to obtain a system able to assess the sustainability performance since the early design stage. The connection between the two indexes allows assessing the real estate, characterizing each building with a performance level and evaluating the feasible sustainability improvements.

Keywords: Real Estate, Efficiency, Sustainability, Multicriteria, Anomalies

1. Introduction

In these last years the importance of the refurbishment of the real estate rapidly increased due to the economic crysis and the necessity to reuse existing buildings (due to the impossibility of building new constructions). Making the correct choices could lead to appreciable savings and doing this at its best requires a good knowledge of the building. A large numbers of methods were identified: Facility Performance Evaluation Zimring (2010), Building Condition Assessment Abbot, Mc Duling, Parsons, Schoeman (2007), The Stonewell Group Inc. (2006), Standard & Poor's (1995), Foltz, MCkay (2008), Ahluwalia

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(2008), Queensland Government (2011), Ezovski (2009), Straub (2002), ASCE 30-00 (2000). All these methods are mainly supposed to be instruments (tools) able to lead the users to the best choices for maintenance, in both short and long terms. This work, instead, is aimed at proposing a method able to both assess the current state of a building and evaluate the possible refurbishment strategies in terms of sustainability. The main objectives are: the creation of so called *efficiency indexes* of existing buildings and the identification of a method able to evaluate project alternatives and choose the best one. An application of the method to a building of the Politecnico di Milano Campus is shown as a case study. In this example, criticalities and strengths of the method have been evaluated using an iterative process.

2. Building efficiency indexes

The idea of creating *efficiency indexes* for the condition assessment of buildings was born together with the necessity to create and manage a well-organized building logbook, that allows stakeholders (owners, users and technicians) to get a better and faster analysis of the building itself. This work highlighted the necessity of mainly two types of indexes: one (documental) to describe the quality and quantity of available building documents taking into account legal requirements; the other (technical) to assess the building condition in terms of aging and anomalies of its components.

2.1. Documental efficiency index

The first index is organized as a weighted ratio between the number of available documents and the number of documents that should be available for the specific building. This ratio involves weights able to consider the different importance of all documents related building design, construction and operation. A list of required documents is the starting point for the documental index evaluation: in this study 9 documents families have been created to classify each document, needed either by law or by standard practice. These nine families do not list documents strictly related to industrial activities done inside the building (i. e. operation and maintenance documentation for industrial plants). The nine families of documents have been weighted with a pair comparison system to get their relative importance; the results are shown in the **Error! Reference source not found.**.

Table 1 – Weights of the 9 documents families

FAMILY	WEIGHT [%]	FAMILY	WEIGHT [%]
Construction	8.41%	Urban planning	3.64%
Fire safety	19.86%	Land registry	2.30%
Structures	26.09%	As-built	12.80%
Plants	17.60%	Provenance and easement	2.14%
Safety and maintenance	7.16%	***TOTAL***	***100.00%***

Some categories may be not necessary for a specific building (i. e. not every building needs fire safety documentation in Italy), so depending on the actual number of families the weight is recalibrated. In addition to these weights, the documents inside each family are organized in four categories according to their importance, with an associated weight: a) Level 1: compulsory documents, which absence implies the illegal or unsafe use of the building; b) Level 2: compulsory documents, which absence does not imply the illegal use of the building; c) Level 3: important documents, not required by the law; and d) Level 4: (non exhaustive) list of documents just with explanatory purpose. The calculation of the documental efficiency index starts with the evaluation of the score of each document, obtained multipling the importance weight and the presence, which is 1 if the document is available and 0 if not.

$$P_{doc} = presence * importance$$

The score of a family of documents is the sum of all the available documents multiplied by their importance weight, as seen in the following equation:

$$P_{eff} = \sum_{i=1}^{n} P_{doc}$$

To obtain the final index for each family, this value is divided by the sum of all the necessary documents multiplied by their importance, as seen in the two following equation:

$$P_{max} = \sum_{i=1}^{n} P_{doc,i}^{necessary}$$

$$P_{family} = \frac{P_{eff}}{P_{max}} * 100\ [\%]$$

The families weight shown in **Error! Reference source not found.** are used in the definition of the documental efficiency index, as shown in the next equation:

$$I_{family} = P_{family} * Weight_{family}\ [\%]$$

So the calculation of the efficiency index for all the families is done by simply summing the weighted indexes of each family, as shown in the following equation:

$$I_{EffDoc} = \sum_{i=1}^{N} I_{family,i}\ [\%]$$

The efficiency index is a number between 0 and 1, where 1 is the best case, all needed documents are available and 0 the worst, no document is available.

2.2. Technical efficiency indexes

The technical efficiency index is used to assess building condition, by measuring building components degradation and their service life. This index is made by three sub-indexes: the first two comparing the actual service life of each component with its reference one (called *service life index*) and the third one evaluating anomalies found on each building component (called *degradation index*). Since the technical efficiency index of a building is a function of the indexes of its components, a standard WBS (Work Breakdown Structure) has been created. This WBS, following UNI 8290 standard, has been organized through 5 levels, from the more general to the more detailed: 1. class of technological units; 2. technological units; 3. class of technological elements; 4. technological elements typology; 5. elements material. The index is calculated for both technological elements (i.e. components; level 3) and technological units (level 2); the other three levels are just useful for organization and comprehension of the WBS. The different importance of each component of the WBS has been taken into account calculating two different series of weights: the first related to the economic value and the second related to the criticality of each component. Both weights have been calculated and applied at the technological units level (level 2). The economic weight is proportional to the percentage contribution of each technological unit to the total construction cost. In the following Table 2, for example, the weights used for a residential building are reported. The pair comparison method has been used to assess the relative importance of each technological unit then converted into criticality weight. All the 18 technological units have been compared to get the results shown in the following Table 2. The two lists of weights are used to build the technological efficiency indexes.

Table 2 – Economic and criticality weights used

#	TECH. UNIT	ECONOMIC WEIGHT [%]	CRITICALITY WEIGHT [%]
1	Foundation structures	2.75%	13,32%
2	Retaining structures	2.75%	9,80%
3	Elevation structures	19.50%	12,88%
4	Vertical Opaque Shell	9.85%	5,55%
5	Vertical Transparent Shell	5.85%	5,20%
6	Slab on ground	1.85%	0,79%
7	Slab on external spaces	0.75%	1,60%
8	Roof	5.05%	9,25%
9	Vertical Internal Partitions	10.85%	1,43%

#	TECH. UNIT	ECONOMIC WEIGHT [%]	CRITICALITY WEIGHT [%]
10	Horizontal Internal Partitions	8.15%	1,76%
11	Vertical External Partitions	1.05%	0,67%
12	Horizontal External Partitions	2.30%	0,67%
13	HVAC	12.70%	3,92%
14	Water and sanitary plant	6.65%	6,28%
15	Electrics and special plants	6.55%	6,01%
16	Sewage disposal	1.35%	3,81%
17	Lift plant	1.80%	3,36%
18	Fire system	0.25%	13,72%

Another instrument needed for the computation of the efficiency indexes is a RSL (Reference Service Life) database that has been built starting from a literary review of major existing databases and from experts' interviews. A list (and a classification) of all possible anomalies for each component is another important necessary element for the calculation of the efficiency indexes. First of all, building components anomalies have been classified, according to the magnitude of their damages on the component itself, in: a) minors; b) medium; c) serious. Anomalies are also classified according to the typology: bistable (on/off - 0%-100%) and non-bistable, with evaluation of the extension (low 25%, medium-low 50%, medium-high 75%, high 100%). Each anomaly has a univocal code, a name, a description and a measuring parameter. The complete list is made by totally 431 anomalies and each component has meanly 12 anomalies, for a total of 5100 possible cases.

It is trivial that in a building there is not the contemporaneous presence of all the components of the database. Each building component can be evaluated using a diagnostic form, which consists of four parts: a) form data (code, name, number); b) component data (code, name, notes, ASL Actual Service Life); c) anomalies check list (with the possibility to select the anomalies for the component and, if necessary, to put the extension); d) indexes output (automatically calculated as soon as the data are entered). Totally 438 forms, one per each possible component of a building, have been created. These forms are collected in 18 folders, which correspond to the 18 technological units of the WBS. The building technological efficiency index is made by three sub-indexes, the first two are the *service life indexes*. They are alternative, D^+ for components with ASL≤RSL and D^- for components with ASL>RSL:

$$D_C^+ = \frac{RSL-ASL}{RSL}\ [-]\ D_C^- = 1 - \frac{ASL-RSL}{ASL}\ [-]$$

Once the service life indexes for each component are known the same indexes can be computed for the upper level of the WBS. The indexes for each technological unit of the building are obtained with the following two equations:

$$D_{UT}^+ = \frac{\sum_{i=1}^{n} D_{C,i}^+}{i}\ [-]\quad D_{UT}^- = \frac{\sum_{j=1}^{m} D_{C,j}^-}{j}\ [-]$$

These formulas are simply the average of the previously calculated index. The last step consists in the evaluation of the service life indexes for the entire building by performing a weighted average of the indexes of the 18 technological units using weights described in Table 2:

$$D_B^+ = \frac{\sum_{k=1}^{o} D_{UT,k}^+ * (P_k^E + P_k^C)}{\sum_{k=1}^{o} P_k^E + P_k^T}\ [-]\quad D_B^- = \frac{\sum_{x=1}^{p} D_{UT,x}^+ * (P_x^E + P_x^C)}{\sum_{x=1}^{o} P_x^E + P_x^T}\ [-]$$

In this work these two outputs are supposed not to be aggregated because they describe two different categories of components and an average could bring to a loss of important information. On the other hand, the degradation index consists of three equations at the component level:

$$A_M = \frac{\sum_{i=1}^{M} P_{M,i} * E_i}{M}\ [-]\ A_S = \frac{\sum_{j=1}^{S} P_{S,j} * E_j}{S}\ [-]\ A_G = \frac{\sum_{k=1}^{G} P_{G,k} * E_k}{G}\ [-]$$

These three partial indexes have to be aggregated in one, describing the component situation, through a weighted average:

$$A_C = \frac{A_M * G_M + A_S * G_S + A_G * G_G}{(G_M + G_S + G_G) = 1} = A_M * G_M + A_S * G_S + A_G * G_G [-]$$

The next step, as in the duration indexes, is the calculation of the index at the technological unit level:

$$A_{UT} = \frac{\sum_{i=1}^{n} A_{C,i}}{i} [-]$$

The evaluation of the efficiency index at the building level uses the same weights and the same equations of the duration indexes:

$$A_B = \frac{\sum_{k=1}^{n} A_{UT,k} * \left(P_k^E + P_k^C\right)}{\sum_{k=1}^{n} P_k^E + P_k^C} [-]$$

2.3. Aggregation of the indexes

The last problem concerning the condition assessment of a building is the aggregation of the four indexes. The question is: is one index better than two or three or four ones? Many options could be evaluated: a) 4 different efficiency indexes (documental, 2 duration, 1 degradation), b) 3 different efficiency indexes (documental, duration, degradation), c) 2 different efficiency indexes (documental and technical) and d) 1 efficiency index (collecting all the previous). The main problem is the information lost during the calculation and not the aggregation (which is only an analytical problem): for an inexperienced user one index can be simpler than four but the information given by a single index could be misunderstood without an appropriate explanation (such as a detailed report). Therefore, in this work it has been decided to keep four separated indexes to better understand the possible criticalities. This aggregation process does not influence the calculation process explained before. The power of the presented method lies in the possibility to evaluate either some components alone or the whole building, without affecting the results.

3. Sustainability multi-criteria analysis method

A Multi-Criteria Method was chosen to collect existing instruments for (Environmental, Economic and Social) Sustainability assessment and for performance assessment of project alternatives. To the Sustainability of a project alternative means to evaluate some benchmarks such as: the whole life-cycle costs for the Economic Sustainability, the embodied energy, the CO_2, the thermal and electric energy demand for the Environmental one, and the thermal comfort, the air speed and air quality, the acoustic comfort and the illumination level for the Social Sustainability. The number of parameters should be established in connection with the analysed interventions. The output of the presented method is a ranking of the most sustainable project alternatives, with the aim to help the designer in the selection of the most suitable one. The method, called SMCAM (Sustainability Multi-Criteria Analysis Method) is created in such a way that it allows evaluating interventions of different categories, so one alternative does not have to exclude the other: it is possible to evaluate combination of different alternatives to get the best solution in terms of Sustainability. A large amount of parameters has been evaluated, starting from International Standards and other research projects with the same theme Open House (2011), Akadiri (2011). These parameters are divided into three major categories, as written in the EN 15643 (2010). In this study the social sustainability has been converted into the internal performance, measured in terms of internal comfort perceived by the occupants. For the environmental assessment of sustainability six parameters have been chosen, starting from the analysis of the requirements of a building, both compulsory and voluntary. They have been divided in two subcategories: environmental impact and energy and resources consumption. The parameters used for the economical assessment are those that, assembled together, give the entire cost on the life cycle of an asset. The disposal cost has not been considered in this research because of two main reasons: the great uncertainty in its calculation (the disposal cost will occur at the end of the life cycle of a building, in our case study 60 years) and its low influence, as showed by the results of a sensitivity analysis; so the effort to add the evaluation of the disposal cost could not give better and more accurate results. The internal performance has been evaluated through the assessment of five main parameters related with the internal comfort. All the parameters can be seen in the Table 3. The method is built according to the AHP selection process Kaklauskas, Zavadskas, Raslanas (2005) and Sonmez, Ontepeli (2009). The first phase consists in the creation of the hierarchic scale, made by three levels and reported in Figure 1.

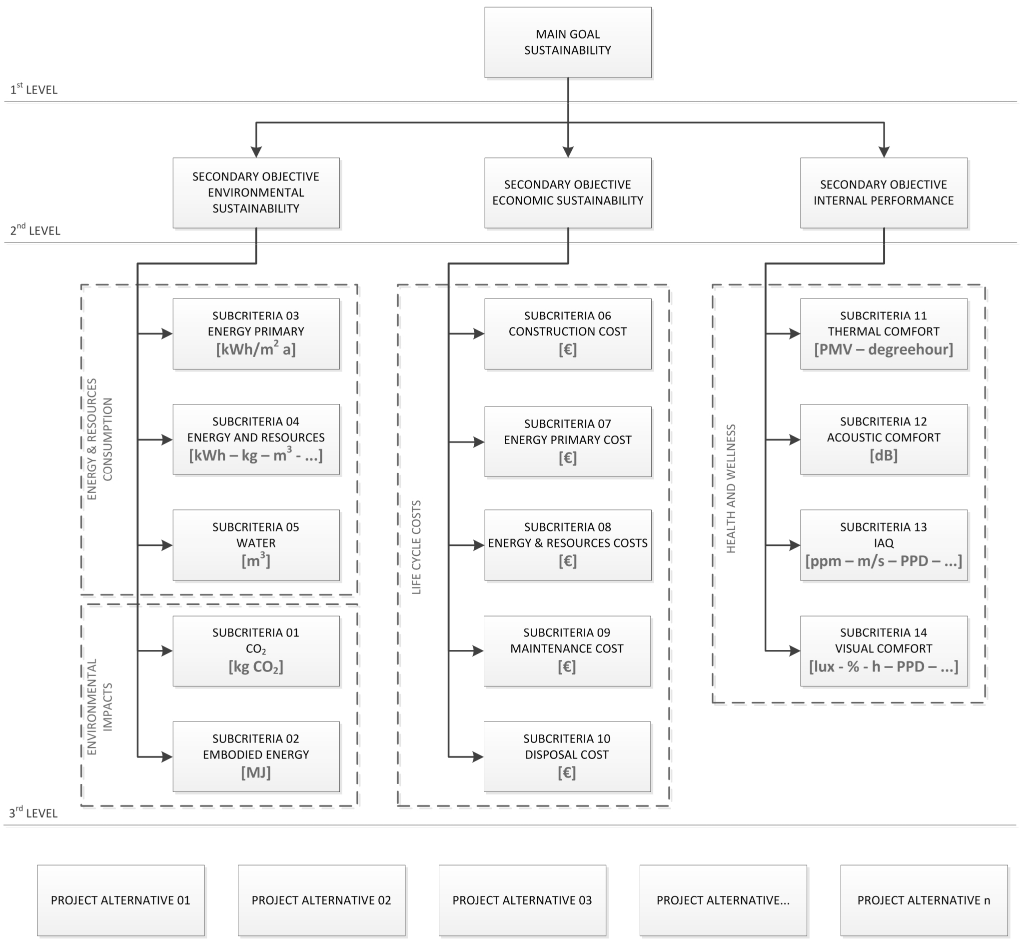

Figure 1 – Hierarchic scale of the SMCAM method

The project alternatives are in the bottom of the hierarchic scale, out of the three levels. The evaluation of different parameters by different units of measure and magnitude requires a normalization process, which can be obviously made in many different ways. In this study the normalization method with equally distributed scale has been used, both for parameters that need to be maximized or minimized. This process is really useful because it normalizes the parameters giving as result 1 for the best solution and 0 for the worst one; this simplifies the entire process of selection, avoiding misunderstanding and errors. In this method a weighting system able to consider the relative importance between parameters seemed to be convenient, so a pair comparison among the elements of the second and third level of the hierarchic scale was conducted; the comparison was performed among elements of the same category (the three fields of sustainability) to get three series of weights. First of all, the relative importance of the fields of sustainability has been calculated, with the following results: a) environmental sustainability 55%, b) economical sustainability 21% and c) internal performance 24%. Then the relative importance of the parameters listed above has been calculated with the same method. The results are shown in the Table 3.

Table 3 – Relative importance of the parameters

PARAMETERS	WEIGHT [%]
ENV_Consumption of energy primary	37%
ENV_Consumption of energy and resources	23%
ENV_Water consumption	17%
ENV_CO_2 emissions	13%
ENV_Embodied energy	11%
ECO_Construction cost	33%
ECO_Cost of energy primary	27%

PARAMETERS	WEIGHT [%]
ECO_Cost of energy and resources	19%
ECO_Maintenance cost	13%
ECO_Disposal cost	7%
PERF_Thermal comfort	46%
PERF_Acoustic comfort	24%
PERF_Internal Air Quality	19%
PERF_Internal visual comfort	12%

The evaluation of the parameters was carried on by an online survey sent to a great amount of people, consisting mainly of professionals, professors, students of Architecture and Engineering. After the comparison, the alternatives could be analysed by collecting the data and calculating the related parameters. This last phase is the easiest from the mathematical point of view but it requires a strong reasoning. The method really helps in the decision phase because it allows the comparison at the third and the second level of the hierarchic scale; so the user can compare both the final and the partial ranking (environment, economy and internal performances) to better understand which solution fits best the objectives.

4. Case study

The first case study expressly selected to test the efficiency indexes and the SMCAM method consists of a building of the Leonardo Campus of the Politecnico di Milano, in Milan – Italy. The building is composed of classrooms distributed on 5 floors and offices and labs of various departments distributed on 8 floors. It has been built in the sixties so the main (the most interesting for this work) technologies are:

- slabs in concrete;
- pillars and beams both in concrete and steel;

- opaque envelope composed by a double layer of bricks with a gap in the middle, without insulation;
- windows with one glazing and steel frame without thermal cut;
- plane roof without thermal insulation;
- heating system with radiators in the classrooms;
- heating and cooling system with fan-coils in the offices.

4.1. Analysis of the current situation

Eight technological units have been analysed through the assessment of their components with the diagnostic forms. Totally 31 elements have been evaluated. Some criticalities came out from this work: there are many anomalies in the windows and in the external finishing of the envelope and the analysed plants (heating and electric), despite the lack of serious anomalies, the components seemed to be really obsolete and not responding to the current requirements, because their RSL has been exceeded. For each component (which means for each form) 3 indexes have been calculated: D^+, D^- and A; the documental situation of the building has not been evaluated. Then, the indexes have been evaluated at the technological unit level using a simple average within the components of each technological unit. The last phase gave the indexes at the building level using a weighted average. In the following *Table 4* the results are shown.

Table 4 – Efficiency Indexes at the building level

TECHNOLOGICAL UNIT DATA		WEIGHTS [%]	WEIGHTED EFFICIENCY INDEXES		
NAME	N. FORMS	TOTAL	D^+	D^-	A
Vertical Opaque Shell	5	15.40%	6.93%	13.11%	11.40%
Vertical Transparent Shell	3	11.05%	-	8.09%	4.83%
Roof	2	14.30%	-	7.15%	13.68%
Vertical Internal Partitions	4	12.28%	5.82%	-	11.10%
Horizontal Internal Partitions	4	9.91%	6.06%	7.57%	9.18%
HVAC	7	16.62%	10.55%	7.39%	16.20%
Electrics and special plants	4	12.56%	5.23%	-	11.78%
Lift plant	2	5.16%	3.87%	-	4.78%
BUILDING EFFICIENCY INDEXES			***39.54%***	***44.52%***	***85.27%***

The symbol - means that in the technological unit considered all the components are under or below their RSL. The results show that most of the components are reaching the RSL limit (D^+ is really low) and a lot of them have also exceeded this limit (D^- is near 50%). The level of anomalies seems to be good (85% is pretty high) but the values of the single technological units show that there are few problems in the envelope: the performances of the windows are really low and the external finishing is detaching. The plants are working but they do not really satisfy the current requirements since they are quite old and they need a strong refurbishment.

4.2. Project alternatives selection

Following the complete evaluation of the current state of the building, some project alternatives have been evaluated to get the best refurbishment solution in terms of sustainability. These possible solutions have been designed to solve the above-mentioned major criticalities. These alternatives have been studied because this building is part of a refurbishment program inside the bigger project “Campus Sostenibile – Città studi” and there is the possibility to concretely implement these solutions. The alternatives studied concern the technological units listed above: envelope, both opaque and transparent, roof, heating, cooling and electric plants. Many alternatives for each category have been studied, up to 44 totally. For each alternative all the fourteen parameters described above have been calculated with different techniques, depending on the degree of precision required and the data available. A BIM model of the entire building has been created to easily manage the alternatives and their related data. The phase after the calculation of the various parameters is represented by the correct application of the SMCAM method, as described in §3. So, the alternatives have been normalized and weighted using the weights of the Table 3 to get the rankings, that can be seen as sustainability indexes of the alternatives. These indexes could be partial (connected to just one branch of sustainability) or comprehensive of all the three major fields. Five alternatives have been selected according these criteria: the most sustainable alternatives overall and the necessary alternatives (which means alternatives connected to components with really low performances, not depending on the improvement of sustainability). The selected alternatives are listed in the *Table 5*.

Table 5 – Sustainability indexes for the selected alternatives

#	COMPONENT	CODE	ENVIRONMENTAL S.	ECONOMIC S.	INTERNAL PERFORMANCE	GLOBAL S.
1	Windows	A.01	0.3647	0.1251	0.0838	0.5737
2	Illumination	A.02	0.3728	0.1481	0.0471	0.5681
3	Heating system	A.03	0.2515	0.1430	0.0192	0.4138
4	Concrete panels	A.04	0.1844	0.1285	0.0192	0.3322
5	Concrete-framed glass panel	A.05	0.1788	0.1269	0.0192	0.3250

The first three alternatives bring serious improvements to the building; on the other hand, the last two are necessary because the concrete panels and the concrete-framed glass panel show really low performances and they require prompt replacement. The five alternatives have been aggregated to make a final comparison with the current situation of the building. The 14 parameters have been calculated without using the SMCAM method, because this phase is aimed at checking the solution. The *Table* shows a large performance increase in terms of environment and economy, and also a good upgrade in the internal performance level. The initial cost is obviously high but the 5 selected interventions should be distributed during years.

Table 6 – Comparison with the actual situation

PARAMETER	CURRENT STATE	SELECTED ALTERNATIVES	Δ [%]
EP_H [kWh_{term}/m^2 a]	141.59	33.55	-76.31%
EP_C [kWh_{term}/m^2 a]	36.15	33.6	-7.06%
ELECTRICITY [kWh_{elet}/m^2 a]	63.94	52.43	-18.00%
CO_2 [kg CO_2/m^2 a]	45.15	27.04	-40.11%
EE [MJ/m^2]	1,137	1,399	23.07%
INITIAL COST [€]	0	604,882	-
MAINTENANCE COST [€]	2,774,435	2,492,588	-10.16%
EP_H COST [€]	2,433,234	576,534	-76.31%
EP_C COST [€]	299,687	278,535	-7.06%
ELECTRICITY COST [€]	2,955,131	2,423,208	-18.00%
LCC [€]	8,690,734	6,375,746	-24.66%
THERMAL COMFORT [degreehour hot]	97,147	103,869	6.47%
THERMAL COMFORT [degreehour cold]	404,564	385,182	-5.03%
ACOUSTIC COMFORT [dB]	39.33	45.21	-13.01%
IAQ [PPD]	54.90%	54.90%	0.00%
VISUAL COMFORT [PPD]	30%	10%	-66.67%

This case study is part of the bigger project “Campus Sostenibile – Città Studi” that is aimed at refurbishing the campus and making it more sustainable. The good piece of news is that two of the previously analysed alternatives (windows replacement and implementation of the illumination system) are now in the construction phase. The other alternatives will be evaluated in the next months.

5. Conclusions

The efficiency indexes and the sustainability index obtained using the SMCAM method, combined together, resulted very useful for the comparison of different feasible solutions in a building refurbishment project. The efficiency indexes are powerful tools for designers, technicians and building users; the indexes are able to give a score to buildings, and a quick report with the explanation of the assessment. Furthermore, the SMCAM method helps the designers during the selection process of the project alternatives and it is also a useful tool for the dialogue with the customer.

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