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*Article*

# Improvement of the Sustainability of Existing School Buildings According to the Leadership in Energy and Environmental Design (LEED)® Protocol: A Case Study in Italy

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**Abstract:** School-age students spend much of their time in school buildings. The sustainability of these buildings should be a priority as better comfort with a high indoor air quality contributes to an improvement in the conditions for learning. Although new school buildings are often built with high standards of sustainability and energy efficiency, the existing school building stock is generally characterised by very poor quality. The energy retrofit of existing school buildings in recent years is part of the policies of the European Union and, consequently, of the Member States. However, rarely do these measures consider aspects other than energy. This paper proposes and discusses a feasibility study which provides a considerable improvement in the environmental quality of 14 school buildings located in northern Italy: the objective is to ensure the requirements for Leadership in Energy and Environmental Design (LEED)® certification. The analysis considers both the technical and economic aspects. The study shows that there is a technical feasibility: the credits are between 42 and 54, moreover the major cost (the cost of building envelope and heating systems retrofit is 82.9% of the total cost) is due to the improvement of energy efficiency. The improvement of sustainability is therefore a reasonable strategy even if the application of the LEED Protocol in the Italian context involves some critical issues that are discussed in the paper.

**Keywords:** sustainability of school buildings; school buildings retrofit; LEED protocol; Green Energy Audit; energy efficiency; economical evaluation of sustainable retrofit

## 1. Introduction

Sustainability in the building sector is a concept that considers the impact of the building with respect to the environment and energy generation and usage, but also considers the well-being of the people living inside the building and the economic aspects.

As described by the ISO 15392 standard [1] sustainability involves three primary aspects which are mutually interdependent and interrelated: the environmental aspect, the economic aspect and the social aspect. In order to "measure" the sustainability of buildings, certification protocols, such as Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM) and Comprehensive Assessment System for Built Environment Efficiency (CASBEE) have been proposed and are managed by non-profit, independent and internationally recognised Associations.

According to the above-mentioned sustainability principles, the certification protocols are not limited to consideration of the consumption of natural resources (energy and potable water), but also, thermal and acoustic comfort and the use of materials that do not emit harmful substances.

The importance of these issues increases further when referred to school buildings, in which the occupants are students/children pursuing a learning activity. The sustainability protocols aimed at making schools sustainable evaluate the building in terms of energy efficiency (less cost to public administration), health and comfort (which help the development of students) and the way in which the structure itself becomes an element from which to learn sustainability strategies.

The achievement of sustainability in the protocols which certify it requires an integrated assessment of different aspects where those related to energy end atmosphere are the most important in terms of weight in the final assessment. For example LEED for Schools New Constructions and Major Renovations [2] assigns a weighting of 30% for the category Energy and Atmosphere (EA).

The European Union (EU) has given careful consideration to public buildings by using specific legislation and has targeted projects for economic support. The Directive 31/2010/UE [3], called "Energy Performance Building Directive (EPBD) recast", increases the efforts to promote the energy efficiency of buildings, further raising energy standards for new buildings but also for existing buildings when they are undergoing major renovation.

The EPBD recast Directive states in its Article 9 that "Member States shall furthermore, following the leading example of the public sector, develop policies and take measures such as the setting of targets in order to stimulate the transformation of buildings that are refurbished into nearly zero-energy buildings".

The EU's interest in the energy renovation of public buildings is confirmed by the Directive 2012/27/UE [4]: its Article 5 states that "Member State shall ensure that, as from 1 January 2014, 3% of the total floor area of heated and/or cooled buildings owned and occupied by its central government is renovated each year to meet at least the minimum energy performance requirements that it has set in application of Article 4 of Directive 2010/31/EU".

In order to facilitate the mobilisation of funds for investments in sustainable energy at the local level, the European Commission and the European Investment Bank have established the European Local Energy Assistance (ELENA) technical assistance facility, financed through the Intelligent Energy-Europe programme. ELENA support covers a share of the cost for the technical support that is necessary to prepare, implement and finance the investment programme. ELENA assistance could well facilitate access to the European Bank of investments financing or financing from another bank.

For public administration and services access to credit represents a barrier to the implementation of measures to improve the sustainability despite the many economic benefits to be obtained from green buildings, including the reduction of operational energy costs.

The issue of energy performance and energy management in public buildings has been the subject of several significant publications. Many authors have carried out research addressing the different aspects of improving energy efficiency in existing school buildings, considering also issues related to the internal air quality: Butala and Novak [5], Santamouris *et al.* [6], Dimoudi and Kosterala [7], Theodosiou and Ordoumpozanis [8], Becker, Goldberger and Paciuk [9], Butala, Gričar, and Novak [10].

As far as the Italian context is concerned, Dall'O' and Sarto [11] proposed a study concerning an energy audit campaign conducted on 49 school building complexes located in the Lombardy region of Italy. Different energy retrofit scenarios were studied with different performance and cost-effectiveness targets: the results show that it is not always convenient to excessively improve energy performance for heating.

Some studies analyse the issues related to environmental sustainability of school buildings. The McGraw-Hill Construction [12] survey underlines that over 80% of the K–12 and higher education schools surveyed have conducted at least some green retrofits and operational improvements. Like other sectors, schools are driven by the goal of saving money and quantify effectively not only energy and water benefits but also other benefits (health, reducing respiratory illnesses and absenteeism and improving learning abilities of students) as essential to support the case for future investments in green building and retrofits.

Interesting studies have been conducted regarding energy consumption and Indoor Air Quality (IAQ) in schools by Greek universities. Dimoudi [13] analyzes the energy performance of school buildings at the primary and secondary education level located at northern Greece, covering the C and the D climatic zones. In order to homogenize the recorded energy consumption data, they were normalized regarding climate characteristics. The normalized energy consumption has a mean value of 41 $kW·h/m^2$, while insulated buildings show 39 $kW·h/m^2$, and non-insulated buildings 43 $kW·h/m^2$. Energy savings can be obtained at school buildings providing considerable cost savings while improving indoor thermal conditions. School buildings have mainly heating energy needs, and thus it is important to investigate measures to reduce heating energy. Insulation of external walls results at reduction of the energy consumption up to 12% at the C climatic zone and by 13% by insulating the building support frame at school buildings at the D climatic zone that have insulation only on the walls and ceiling. Considerable energy savings can be achieved with good windows airtightness, which for the D climatic zone may reach a reduction up to 6%. Although schools operate for a short period during the cooling period, indoor overheating conditions can be avoided with simple and relatively inexpensive measures (proper shading, nigh ventilation, ceiling fans, external surface colour). These measures can contribute to considerable cooling energy reduction by up to 64% by applying ceiling fans at the C climatic zone and by eliminating the cooling load with night ventilation at the D climatic zone (about 99% reduction).

The conclusion is that with the EPBD recast demand for "Nearly zero energy buildings" by 2018 for public buildings, the combined application of energy-saving measures in order to reduce energy needs and Renewable Energy Systems (RES) systems to cover the remained energy needs allows for investigation of different systems combination in order to cover the varying energy needs according the size, shape and location of school buildings.

Dascalakia and Sermpetzogloub [14] have studied in detail the issue of the indoor environmental quality and the energy consumption of Hellenic school buildings, even for recently constructed school buildings. The general features of the contemporary building stock are presented along with the results from an energy survey in 135 Hellenic schools. The derived energy consumption benchmarks are compared with published literature. Finally, the energy performance and indoor environmental quality of a representative sample of schools in metropolitan Athens are assessed in a holistic approach to the "energy efficiency–thermal comfort–indoor air quality" dilemma. The Indoor Environmental Quality (IEQ) assessment was based on an objective evaluation by monitoring crucial indoor conditions and a subjective occupant evaluation using standardized questionnaires. The available official data on the construction characteristics of Hellenic schools reveal that 59% of the buildings are up to 30 years old, while only 13% of the schools occupy buildings that were not specifically designed and constructed for this purpose. Despite some refurbishments that schools have periodically implemented, about two-thirds of the school buildings fail to meet the standard requirements regarding their thermal envelope construction (e.g., insufficient insulation, single glazing). Moreover, the absence of proper controls in the operation of heating and lighting systems often leads to irrational use and excessive energy consumption. Lack of appropriate natural ventilation is often responsible for the deteriorated classroom IAQ. According to measured indoor conditions, even during the mild spring period of monitoring, on average, 60% of the recorded indoor temperature, one-third of relative humidity and about 17%–35% of $CO_2$ concentrations, were inconsistent with indoor conditions prescribed by international standards. The most frequent IEQ complaints reported during the subjective evaluation are related to insufficient ventilation, noise disturbance, glare and thermal discomfort. So the first step towards reducing the investment cost is to reduce energy demand. In well thermally insulated buildings with high performance heating systems and energy saving light fixtures, the use of controls (e.g., space thermostats, daily timers for lighting) would diminish energy waste attributed to the human factor thus leading to a significant reduction of the related energy demand.

In Italy a full and detailed knowledge of the existing school building stock currently does not exist. The data provided by Italian National Statistics Institute (ISTAT) estimate that the assets include a total of 50,157 national school buildings, divided as follows: 49% nursery schools, 35% primary schools, 16% first level secondary schools. The schools located in the Lombardy region are 6747, corresponding to 13.4% of the national stock.

This paper proposes and discusses a study which provides a considerable improvement in the environmental quality of 14 school buildings (pre-schools, primary and secondary) located in Cesano Boscone and Trezzano sul Naviglio, two Municipalities in Milan Province in Northern Italy. For the school buildings the "Green Energy Audit" (GEA) procedure described in [15,16] was applied, in order to verify the possible improvement of energy efficiency and environmental quality, in accordance with the LEED® for Schools rating system. The objective of the study was to ensure at least the minimum requirements for obtaining LEED® certification. Compared to the state of the art in the study of the topic of the redevelopment of existing school buildings, this study addresses for the first time the issue of the application of a methodology that aims to improve the sustainability in a real context.

## 2. General Aspects and Methodology

### *2.1. General Aspects*

This paper is the result of a study sponsored by a group of researchers from the Architecture, Building Environment and Construction Engineering (ABC) Department at the Polytechnic of Milan (Italy) in cooperation with SACERT, a mixed public and private non-profit association, operating in Italy to promote energy efficiency and sustainability in the private and public building sector. The aim of this study was to verify in the field, and then in actual buildings, the technical and economic feasibility of redeveloping existing school buildings in order to improve not only energy efficiency but also sustainability in accordance with an international protocol. As far as this latter aspect is concerned, the Lombardy Region, unlike many Italian regions, has not officially adopted any scheme, which is why we felt free to choose the most widespread protocol, LEED® promoted in Italy by the Green Building Council Italy (GBCI) [17]. The implementation of a study of public school buildings is not easy from an organisational point of view: one must have permission from the school administration, but above all it is necessary to have an effective technical support for the collection of necessary documents, including energy bills. It is also necessary to have access to the buildings themselves for surveys and measurements. The public sector schools in Italy, from nursery schools to the first level secondary schools are owned by the municipalities (local councils) and for this reason, the first phase of the study consisted in contacting some municipalities of whom was asked their willingness to join this project. Two municipalities, Cesano Boscone and Trezzano sul Naviglio, joined the project by making available 14 schools (pre-schools, primary and secondary) for study. For all the school buildings the GEA procedure [15,16], described in Section 2.3, was applied in order to verify the possible improvement in energy efficiency and environmental quality, according to LEED® rating system. The objective was to ensure the attainment of at least the minimum requirements for obtaining LEED certification whilst maximising the energy aspects.

### *2.2. Description of the LEED® Protocol*

The LEED® environmental certification is a protocol developed and published by the U.S. Green Building Council (USGBC): it provides different formulations depending upon building type and the phase of the building's life cycle. LEED® for New Construction can be used for new buildings and existing buildings subject to major renovations (for interventions that involve significant elements of air conditioning systems, significant interventions on the construction and renovation of interior spaces) [2–17]. LEED® Operations and Maintenance [18] was designed to certify the sustainability of ongoing operations of existing commercial and institutional buildings. LEED® for Schools [19] addresses design and construction activities for both new school buildings and major renovations of existing school buildings. In Italy LEED® certification of a school is carried out by applying the Italian version of LEED® for New Construction and major renovation, with the mandatory integration of the credit on acoustic treatment, as was done in the present study.

The rating system is organised into five environmental categories: Sustainable Site (SS), Water Management (WE), EA, Materials and Resources (MR) and IEQ.

An additional category known as Innovation in Operations (IO) for existing buildings or Innovation in Design (IP) for new construction and renovations addresses innovative practices aimed at sustainability and issues not covered in the five previous categories. The category Regional Priority (PR) is used to highlight the importance of local conditions in determining best practices.

Within each environmental category are defined mandatory prerequisites and credits that allow the acquisition of points. The weighting of the credits is based on scientific methods to guarantee their greater accuracy and transparency. Quantitative methods were introduced to objectively assess the environmental impacts of a building during its entire life cycle.

To earn LEED® certification, the project must satisfy all the prerequisites and qualify for a minimum number of points. The 2009 LEED® certification classifies buildings according to the following rating scale: Base: 40–49 points; Silver: 50–59 points; Gold: 60–79 points; and Platinum: 80 and above.

LEED® is the most popular protocol in the world, and it is one of the most reliable and widely applied. As [20] underlines, LEED® rating systems adopt a holistic evaluation of the overall impact of building on environment. For these reasons LEED® is used as the reference environmental protocol for the GEA.

### *2.3. Description of the Methodology*

Energy audits of buildings are the most effective tool to promote energy retrofitting measures for existing buildings. Energy audits have multiple goals, including reducing energy consumption and managing costs. The methodology of GEA proposed defines an approach that is somewhat different from the traditional one. The added value lies in the word "green", a word that refers to and summarises a common concept: sustainability. The GEA is not intended to be a new energy auditing procedure, but rather a new and more modern interpretation of the classic methodology. In the proposed method the sustainability achieved by applying a retrofit measure is assessed with reference to the LEED Protocol.

The aim of a GEA is to evaluate the degree of improvement in sustainability of the building as a whole that can be obtained through the proposed choices; such choices do not necessarily generate an advantage in terms of energy, but they can generate many advantages with respect to sustainability. If the standard of comparison is the LEED Protocol, then the problem is in understanding how application of a certain remedial action can help to meet the credits. The GEA integrates two strategic elements, energy and environment, by mixing the Energy Audit and LEED® methodologies [21]. This synergy strengthens the role of the classic energy audit by providing a method that not only optimises the energy performance of existing buildings but also achieves a green retrofit of buildings.

The methodological approach of the GEA implicates a series of choices [22]:

- The definition of measures that lead to a reduction in the consumption of resources; conservation of energy then becomes conservation of resources.
- The Auditor must have two objectives: to maximise energy performance and to maximise sustainability.
- Those measures that use renewable energy are preferred.
- When defining measures, the Auditor should consider all natural solutions that can help control the climate and lighting within the building, such as green roofs, green facades, natural shading systems, passive solar and lighting by daylight systems.

- The evaluation of sustainability targets in accordance with the LEED® rating system.

The correlation between the measures for energy and environmental sustainability considered by the GEA and the acquisition of LEED credits is not direct because some measures can contribute to more than one credit.

Any measure of the GEA, is not uniquely linked to a credit. Design choices and credits are therefore two elements between which there is a correlation that is not bi-univocal, as viewed in the entirety of its design choices are compared with the evaluation system. A measure in terms of energy and the environment can meet one or more credit from different LEED categories as a function of the choices being made.

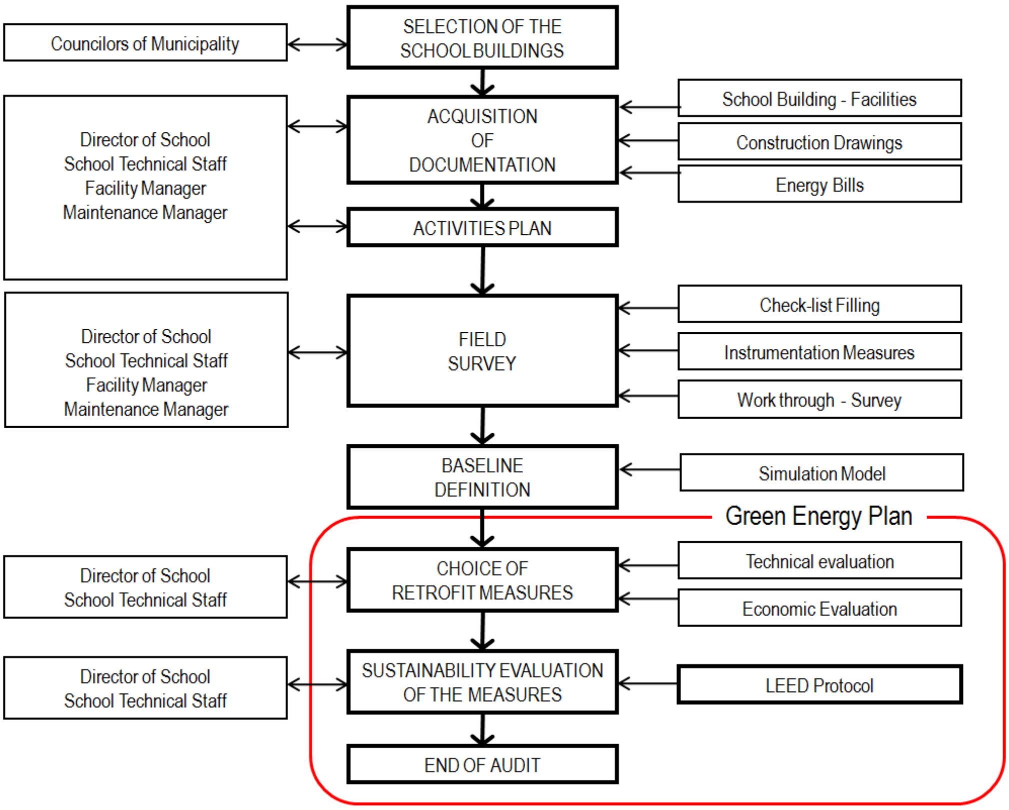
Although LEED certification is given based on an assessment of the building as a whole, the performance of the structures that make up the building and building management strategies can help meet the objectives set by the credits and thus can contribute to the acquisition of final certification for the building.

The GEA process is divided into several phases [23], as a function of the operating level that one wants to apply, the elements contained in the phases may involve greater or lesser detail.

Figure 1 shows the flow diagram of the Auditing Process: the activities are defined on the basis of a series of elements:

- the operational level of the audit (walkthrough, standard or simulation);
- the type of building or installation;
- the size and complexity of building and/or facilities;
- the category of the system to be investigated;
- the owner/client organisation.

**Figure 1.** Flow diagram of the Auditing Process.



The combination of these elements greatly influences the strategy to be adopted, its complexity, its execution time, the commitment of resources and consequently the definition of the Activity Plan according to which the audit is performed. The methodology proposed in this study divides the entire process into the following phases:

- acquisition of documentation (school building facilities, construction drawings and energy bills);
- planning of activities;
- field surveys (check-list compilation, instrumentation measurements and walkthrough surveys);
- definition of the baseline;
- definition of the Green Energy Plan.

For each of the above listed phases one must examine: the purpose and content, the actors involved, the tools, expected documentation and the critical issues. Depending on the objective of the GEA, every stage of the process will be carried out in a more or less detailed manner.

## 3. Application of the Methodology

### *3.1. Technical and Functional Characteristics of School Buildings*

The school building stock analysed includes 14 buildings located in Cesano Boscone and Trezzano sul Naviglio, two small towns near Milan, chosen on the basis of the available documentation and the possibility of access.

As far as the intended uses are concerned, there is a large variety of building types: seven nursery schools, six primary schools and two first-level secondary schools. Three of these school complexes belong to the mixed schools category. Mixed schools are building complexes with more than one intended use (e.g., nursery school + primary school), with more than one building but with a single centralised heating system.

The year of construction of the school building complexes ranges over a wide period, from 1933 to 1984: one building up to 1960 (redeveloped in 1974), four buildings between 1961 and 1970 (one of which was redeveloped in 1984), nine buildings between 1971 and 1980 (one of which was then redeveloped in 1984). The distribution of the construction years is related to the social needs, in terms of the number of children of school age in the period in question. The age of all buildings within a given school building complex are not always the same: in some cases the number of buildings has increased over time, or some buildings had been redeveloped at some stage. Table 1 summarizes the main technical characteristics of the school buildings considered in the study.

The wide variety of building ages presents a scenario consisting of very different buildings, with technological characteristics, types of construction and energy performance which all differ considerably. The total gross volume of the school building complexes investigated is 151,423 m$^3$, therefore an important sample. However, when analysing the individual complexes, widely varying situations become clear: the smallest building has a volume of 2598 m$^3$ and a net surface of 714 m$^2$ whilst the largest one is of 31,345 m$^3$ and a net surface of 5190 m$^2$.

For the assessment of LEED® credits of the SS category, the data collected were the number of occupants (including 131–617), the area of the site and the building footprint. The smallest building occupies a site area of 4491 m$^2$ and the building footprint is equal to 1190 m$^2$ whilst the largest one occupies a site area of 63,322 $m^2$ with a building footprint of 19,187 $m^2$, further proof that the cases examined are representative of the variety of municipal buildings.

**Table 1.** Data of some characteristics of the buildings.

| Building | School type | Construction year | Number of occupants | Net surface ($m^2$) | Volume ($m^3$) | Site area ($m^2$) | Building footprint ($m^2$) |
|---|---|---|---|---|---|---|---|
| #1 | Primary schools | 1965–1966 | 260 | 2,345 | 9,920 | 5,770 | 1,521 |
| #2 | First level secondary school | 1980 | 352 | 5,190 | 31,345 | 8,144 | 2,060 |
| #3 | Primary schools | 1976 | 303 | 3,300 | 21,504 | 18,259 | 2,696 |
| #4 | Primary schools * | 1972 | 238 | 2,805 | 11,634 | 6,339 | 1,980 |
| #5 | Nursery schools * | 1974 | 180 | 1,144 | 5,468 | 5,143 | 1,266 |
| #6 | Primary and first level secondary schools * | 1974 | 617 | 6,019 | 28,808 | 12,210 | 3,302 |
| #7 | Nursery schools * | 1973 | 132 | 688 | 3,045 | 14,974 | 837 |
| #8 | Nursery schools | 1976 | 185 | 1,124 | 4,248 | 4,491 | 1,190 |
| #9 | Nursery schools | 1974–1984 ** | 131 | 714 | 2,598 | 5,132 | 841 |
| #10 | Nursery schools | 1973 | 137 | 1,144 | 5,468 | 4,787 | 1,265 |
| #11 | Primary schools * | 1962 | 253 | 1,833 | 8,120 | 45,608 | 13,799 |
| #12 | Nursery schools * | 1968 | 146 | 876 | 3,478 | 31,246 | 11,300 |
| #13 | Nursery schools | 1933–1974 ** | 137 | 773 | 2,978 | 29,555 | 9,535 |
| #14 | Primary schools | 1966–1984 ** | 242 | 2,882 | 12,809 | 63,322 | 19,187 |

*: Mixed schools; and **: the first date indicates the construction year of the building, the second one the retrofit year.

### *3.2. Acquisition of Information and Field Surveys*

The first step [24] consists in the acquisition of documentation: this is an essential element because a good documentary basis allows one to considerably reduce the "on site" activities. The auditor studying the documents is well-prepared to schedule major assets necessary to integrate the missing information, to identify critical areas in terms of energy and environment, to have objective elements of discussion for the first meeting with the municipal personnel involved.

All the data collected were checked and updated by conducting meetings with the municipal administration. Finally the following documents were also collected:

- updated plans of buildings;
- town Planning Scheme in which the planned services are described, the number of full time equivalent (teachers and school staff) and students, the technical standards of the site.

After having made arrangements with the technical department and having obtained the available documents, auditors and municipal technicians planned the field survey for the compilation of check lists.

Thereafter a field survey was conducted to check the information acquired and to integrate any missing data. In this phase the auditor takes direct vision of the building, installation or infrastructure in order to:

- integrate the technical and management information that could not be deduced from the documentation supplied by the client;

- perform instrumental measurements to gather information that can provide direct evidence with which to evaluate the performance of components or building systems and plant;
- undertake measurements to define the parameters of environmental conditions (comfort evaluation);
- make a first selection of possible actions, verifying the applicability of the same.

For LEED®, the data needed in order to verify the fulfilment of the prerequisites and credits can refer to the two phases of the realization of the work: design and construction. For the design phase were collected data about the actual building in standard operating conditions, while for the construction phase have been consulted an expert LEED® and the head of the technical office. During the survey, the missing data to acquire the necessary information for GEA and LEED® category are collected, in particular:

- for SS: the characteristics of the site area, the presence of alternative transportation and community connectivity, the site development, the heat island effect on roof and non-roof;
- for water efficiency: the presence of services for the water reduction, of water efficient landscaping and of innovative wastewater technologies;
- for EA: the characteristics of the building envelope, characteristics of the facilities, facility management.

### *3.3. Baseline Definition and Energy Evaluation*

The data collected through analysis of documentation provided by the client, integrated by the field surveys, are the basis to understand the performance of buildings and facilities investigated. The baseline stands for the current reference situation with which comparison is made in order to identify and then evaluate the possible retrofit measures.

The "baseline building" is calculated as described in the LEED® Prerequisite 2 "Minimum Energy Performance". The prerequisite requires to demonstrate a 5% improvement in the proposed building performance rating compared with the baseline building performance rating.

Once the baseline has been defined, one proceeds with the definition of retrofit measures for each building in order to obtain the minimum requirements for LEED® certification and to maximise energy performance. Thus one is considering the scenario called "high-performance", proposed in the reference study [11], which involves the following measures:

- The replacement of all the boilers with Ground Source Heat Pump (GSHP), considering an average Coefficient of Performance (COP) of four, with heating power output reduced to fit decreased energy losses due to improvements in envelope insulation.
- The installation of local control systems (*i.e.*, thermostatic valves).
- Thermal wall insulation using External Thermal Insulation Composite Systems (ETICS) technology, of a thickness necessary to reach a $U$-value = 0.28.
- Roof insulation with the thickness necessary to reach a $U$-value = 0.15.
- The replacement of all the windows with high performance windows (triple glazing, low emission and argon) having a $U$-value = 1.1.
- The installation of mechanical air ventilation systems with a heat recovery system, having an recovery efficiency of 70%.
- A polycrystalline photovoltaic system (PV).

The intervention of improvement of heating, ventilation and air conditioning systems considered systems similar to those currently used for near zero energy buildings [25].

In this scenario, mechanical air ventilation systems are installed to ensure compliance with the Italian obligatory health standards for schools. The PV has been sized, using a solar radiation value for the location (average value 1100 kW·h/$m^2$ y), to take into account two aspects: the available and well-oriented space on the roofs and the energy required by the electricity consumption of the GSHP.

The EA category promotes the control of energy performance in three phases: the control of the building energy performance (design, commissioning and monitoring); management of refrigerants to eliminate CFCs and use of renewable energy.

Table 2 shows the results of the calculation for the Prerequisite 2 of the energy section called "optimizing energy performance". The purpose of the Prerequisite is to verify that the level of energy performance requirements for buildings and facilities is higher than that established by the regulations, in order to reduce the economic and environmental impacts associated with excessive energy use.

**Table 2.** Data for primary energy demand and percentage of primary energy savings.

| Building | Primary energy for heating and ventilation (kW·h/$m^3$ y) | Primary energy for domestic hot water (kW·h/$m^3$ y) | Primary energy for lighting (kW·h/$m^3$ y) | Primary energy for process energy (kW·h/$m^3$ y) | Primary energy for renewable energy (kW·h/$m^3$ y) | Emissions savings (t $CO_2$) | Percentage of primary energy savings (%) |
|---|---|---|---|---|---|---|---|
| #1 | 5.65 | 0.27 | 2.58 | 8.32 | 3.36 | 52.64 | 67.6% |
| #2 | 5.71 | 0.12 | 1.80 | 6.35 | 3.32 | 140.89 | 66.4% |
| #3 | 6.77 | 0.15 | 1.67 | 6.44 | 3.62 | 79.51 | 64.6% |
| #4 | 6.73 | 0.21 | 2.63 | 9.19 | 5.87 | 67.51 | 72.0% |
| #5 | 7.92 | 0.34 | 2.28 | 8.66 | 2.90 | 28.90 | 62.4% |
| #6 | 5.81 | 0.55 | 2.63 | 8.88 | 3.11 | 163.29 | 66.8% |
| #7 | 9.57 | 0.45 | 2.46 | 8.54 | 6.73 | 14.20 | 66.5% |
| #8 | 9.76 | 0.45 | 2.88 | 10.48 | 5.67 | 26.16 | 65.8% |
| #9 | 12.96 | 0.52 | 3.00 | 11.71 | 11.47 | 16.85 | 71.4% |
| #10 | 9.91 | 0.26 | 2.28 | 7.20 | 6.81 | 19.50 | 64.3% |
| #11 | 10.65 | 0.23 | 3.60 | 10.61 | 4.54 | 48.22 | 61.3% |
| #12 | 10.68 | 0.44 | 1.95 | 10.94 | 10.13 | 22.73 | 74.6% |
| #13 | 10.97 | 0.48 | 3.29 | 11.55 | 7.27 | 19.89 | 67.1% |
| #14 | 8.38 | 0.20 | 2.30 | 9.62 | 6.33 | 75.10 | 70.5% |

The energy performance of the building is given by the sum of the primary energy requirements for winter heating and summer, for the production of domestic hot water, for lighting and power requirements of the processes, including the contribution made from energy production from renewable energy plants.

Concerning the renovations, the primary energy consumption of the reference building called the "baseline building" and the project building are compared. The score is given through the verification of the following limits:

- 5%, prerequisite;
- 10%, 1 point;

- 15%, 2 points;
- more than 15%, 3 points.

where the percentage reduction in total primary energy demand $PE_{red}$ of the building is calculated with the following equation:

$$PE_{red} = \left(1 - \frac{EP_{HV}+EP_{DHW}+EP_{L}+EP_{PE}-EP_{RE}}{EP_{HV,lim}+EP_{DHW,lim}+EP_{L,lim}+EP_{PE}}\right) \times 100 \quad (1)$$

The parameters of the Equation (1) were calculated as follows:

- Primary Energy for Heating and Ventilation ($EP_{HV}$). In order to evaluate the energy requirement for heating and ventilation of the building—baseline and high performance scenario—a standard approach is used for the energy evaluations which is in accordance with the official calculation method adopted in the Lombardy Region (Italy) [11].
- The remaining indicators were calculated according to the LEED procedure of calculation based on UNI/TS 11300 [26,27] first and second part, UNI EN 15192 [28] and ASHRAE 90.14 [29], being in more detail:
    - Primary Energy for Domestic Hot Water ($EP_{DHW}$): the value is determined on the basis of the procedure described in the UNI TS 11300 Part II [27], in according to of the energy system proposed and the number of users of the building. The limit value is calculated using an average production yield of 80%;
    - Primary Energy for Lighting ($EP_{L}$): the value is calculated as the ratio between the Lighting Energy Numeric Indicator (LENI) and the national electricity system performance;
    - Primary Energy for Process Energy ($EP_{PE}$): the value is considered to be equal to 25% of the total consumption of primary energy of the baseline building;
    - Primary Energy for Renewable Energy ($EP_{RE}$): the value is equal to the production of energy from renewable sources of the building.

Table 2 shows also the Green House Gases (GHG) reduction, assessed as total savings of each building, resulting from the implementation of all retrofit measures, and the energy saving for each building school calculated according to the Prerequisite 2.

The total primary energy requirement of the buildings analysed varies from a minimum of 13.99 kW·h/m$^3$ y (for Building #2) to a maximum of 28.9 kW·h/m$^3$ y (for Building #9), with a mean value equal to 18.09 kW·h/m$^3$ y.

The values obtained appear to be quite homogeneous, therefore, one can obtain the following percentages of individual requirements on the total primary energy: the $EP_{HV}$ accounts on average for 32% compared to total primary energy, the $EP_{DHW}$ for 1%, the $EP_{L}$ for 10%, the $EP_{PE}$ for 37%, and the $EP_{RE}$ for 19%. The weight percentage of the hot water is very low: this justifies the choice not to install a solar thermal system to cover this requirement. On the other hand electricity consumption carries on average a high weight, equal to 47% of the total: this supports the choice to install the solar PV system on each building.

The emissions saved vary from a minimum of 14.20 t $CO_2$ (for Building #7) to a maximum of 163.29 t $CO_2$ (for Building #6): the values vary greatly as a function of the gross volumes of the buildings, therefore, the larger buildings have the greatest potential for total energy savings. On the other hand the specific consumption amounted to an average value 4.98 t $CO_2/m^3$ and varies from a minimum of 3.57 t $CO_2/m^3$ to a maximum of 6.68 t $CO_2/m^3$.

### *3.4. Action Plans to Obtain LEED Certification*

In order to obtain LEED® certification, the project must satisfy all the prerequisites and qualify for a minimum number of points. The objective was to ensure at least the minimum requirements for obtaining LEED® certification, thus to meet all prerequisites and to achieve a score to fit into the rating Certified (minimum 40 points).

LEED® provides the option of splitting a certification into two phases: design and construction. In the reference manual of the different protocols LEED® is a table that lists the prerequisites and credits acquirable in the design phase and those under construction. While the credits acquirable in the design phase have been calculated in detail, the prerequisites and credits acquirable during the construction phase (mainly in the categories MR and IEQ) have been assigned or denied on the basis of assumptions of real applicability in the specific case. The assumptions that have led to the assignment of credits acquirable under construction are shown below, for other credits points were not given:

- For SS category: Credit Site Development-Protect or Restore Habitat and Credit was attributed since for school buildings is particularly important to provide a high amount of green open space, protecting and restoring the green areas. Credit Heat Island Effect—Non-roof that was calculated on the basis of the available documentation and site inspections carried out.
- For EA category: Credit Green Power requires one to take out a contract to provide at least 35% of the building’s electricity from renewable sources. The credit was attributed since the purchase of energy from renewable sources is a significant action in terms of commitment of public administration in the environmental field, plus the price of green energy is more and more close to that of the energy is not derived from renewable sources.
- For credits in MR category the assumption is of maintain the existing building structure and to reuse building materials and products so as to reduce demand for virgin materials and reduce waste.
- For the IEQ category, credits on low-emitting materials have been attributed as the goal of reducing the quantity of indoor air contaminants (that are odorous, irritating and/or harmful to the comfort and well-being of installation contractors and occupants) is particularly important in a school building.

The IEQ is an aspect examined in detail in [14] on one school building. The occupant responses from the analyzed school are very interesting:

- Students prioritized the acoustical comfort and cleanness as “problematic” parameters (28% and 32%, respectively), while teachers expressed their dissatisfaction regarding space availability (57%) and cleanness (28%).
- Thermal discomfort was reported by 14% of the teachers and 7% of the students (the reported potential sources were radiators often cold or insufficiently hot, insufficient indoor air temperature control, large spatial variations of indoor air temperature).
- 29% of the teachers and 57% of the students complained about overheating during summer while another 29% of the school management reported feeling cold during the winter.

- 50% of the students reported that they would prefer a lower indoor air temperature.
- Although the overwhelming majority of the teachers found visual and acoustical conditions in the school above average, students reported problematic visual comfort (18%) and acoustical comfort (22%) conditions. Additionally, a significant percentage of teachers (58%) would prefer brighter visual conditions.

Regarding the specific IAQ-related health problems students reported on more symptoms, occurring with higher rate than teachers. This can be attributed to the fact that students spend more time in the classrooms than teachers, but it may also have a psychological origin due to the stress they are under.

Hereafter it would be interesting to carry out a detailed investigation of some schools representative of our study with the cooperation of teachers and students, with the aim to produce an overall assessment of the IEQ school more detailed and to investigate any connections with the $CO_2$ emission.

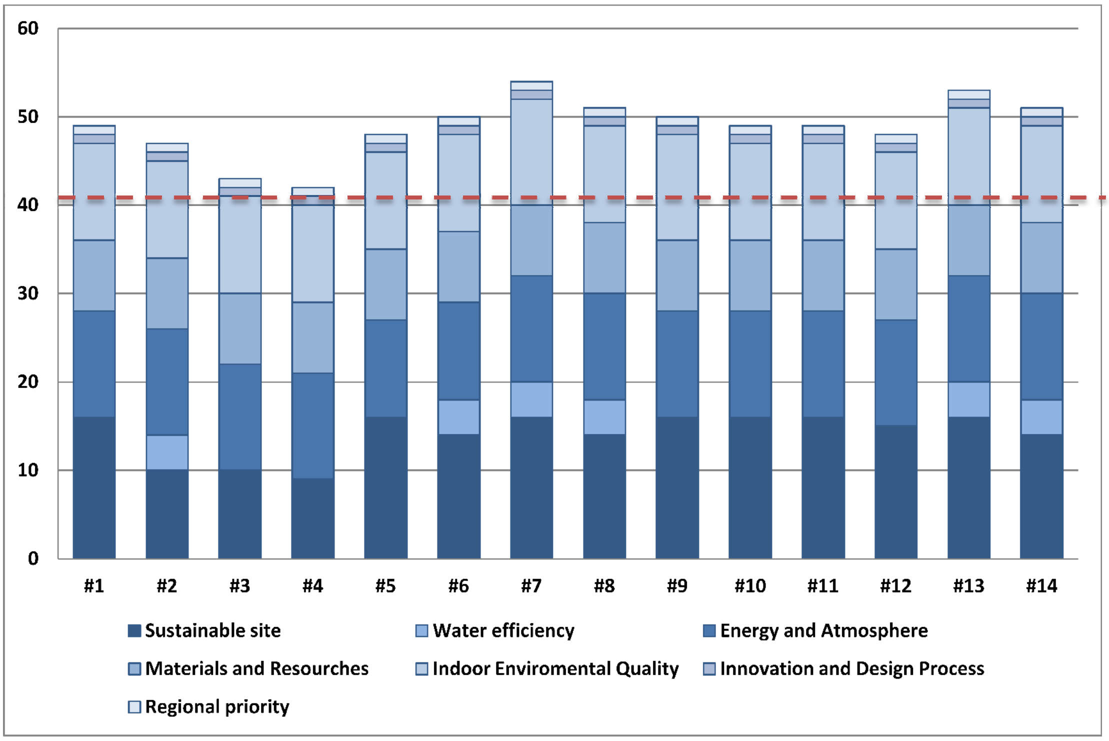
So far as the prerequisites are concerned, Minimum Acoustical Performance requirements can generally be met through the use of sound absorbent materials on ceilings and other surfaces whilst prerequisite Water Use Reduction, according to the calculations, was not satisfied. Then a minimal corrective action to meet this prerequisite was defined by installing in all buildings water flow reducers and double flow toilets. This type of remedial action was then counted in the economic evaluation.

## 4. Results and Discussion

### *4.1. Analysis of the Potential to Improve Sustainability of School Buildings*

To earn LEED® certification, the applicant projects have satisfied all the prerequisites and have qualified for a number of points to attain the minimum established project ratings equal to 40 points (red line in Figure 2).

**Figure 2.** Potential to improve sustainability of school buildings.



Having satisfied the basic prerequisites of the programme, applicant projects are then rated according to their degree of compliance within the rating system: eight buildings fall within the level of Certified with an average score equal to 46.1, while the remaining six reach the Silver with an average score equal to 50.7. Therefore, our objective to achieve LEED® certification for all buildings whilst maximising energy performance, has been achieved.

When comparing the results for category for the buildings, there is the greater variability of results for categories that describe the actual status but a substantial similarity for the credits that contain the design requirements, homogeneous for all buildings.

In particular, the credit SS ranges from 9 to 16, with an average value equal to 12.7. The categories with the greatest impact, calculated with respect to the overall average score of 47.7, are: SS for 26.7%, EA at 24.7%, IEQ with 23.1% and MR which accounts for 16.8%.

For the Water Efficiency category the score of four was awarded only for the buildings in which the use of potable water for landscape irrigation was eliminated.

### *4.2. The Cost of Sustainability: Economic Evaluations*

The economic evaluation [30] was conducted considering costs of retrofits (hard cost) but also soft costs and the cost of Green Building Certification Institute. Cost items considered in the economic evaluation (Table 3) are listed below:

- Building Envelope retrofit cost (which is the total of costs related to thermal wall insulation, roof insulation and the replacement of all the windows with high performance windows);
- Heating Systems retrofit cost (related to the replacement of all the boilers with GSHP and the installation of local control systems);
- Ventilation Systems cost (related to the installation of mechanical air ventilation systems with a heat recovery system);
- Solar PV cost (for the installation of a polycrystalline PV system);
- Green Building Certification Institute cost (related to LEED® certification);
- Soft cost (related to building design that meets LEED® standards);
- Increased renovation cost (related to higher cost of renovation to satisfy LEED® standards);
- Water Efficiency cost (related to installing water flow reducers and double flow toilets).

All costs were then proportioned according to the gross floor area and expressed in (€/m$^2$).

LEED® certification of a building provides for fees to be paid directly to the competent authority, the Green Building Certification Institute. The fees include a registration fee and quotas for the phases of design and construction that vary depending on the size of the building; there are also facilities for local members of the GBCI.

We use the term soft costs to include those activities associated with LEED® that fall outside the range of construction/renovation costs. The soft cost includes the costs of commissioning (which is a prerequisite of the LEED® process), the costs of assessing the energy performance and costs of documenting compliance with the various criteria selected. A significant burden of the LEED® system is this need to document compliance with the various criteria: it does require the establishment of a tracking and reporting system. Based on data from the study [31], an average value was extrapolated for the commissioning process and documentation: a cost of commissioning (base) equal to 1% of the cost of renovation and a cost of documentation of 0.9% was used. The cost of the standard energy performance assessment was assumed to be 5000 € for all buildings.

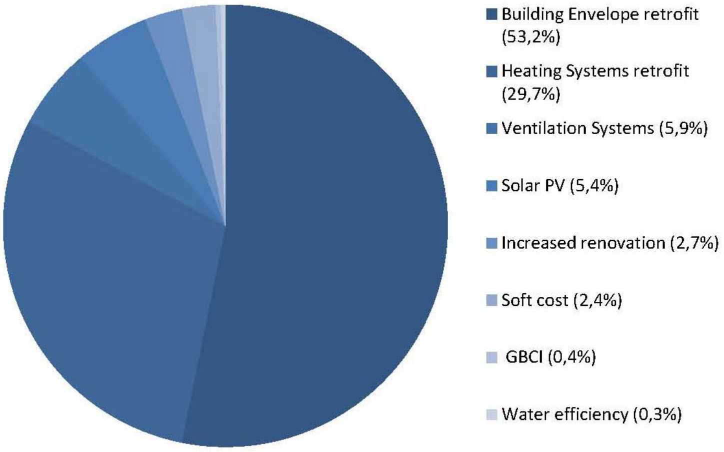
**Table 3.** Costs of sustainability for the school buildings expressed in €/m$^2$. GBCI: Green Building Council Italy; PV: photovoltaic system.

| Building | Net surface (m$^2$) | GBCI cost (€/m$^2$) | Building envelope retrofit cost (€/m$^2$) | Heating systems retrofit cost (€/m$^2$) | Ventilation systems cost (€/m$^2$) | Solar PV cost (€/m$^2$) | Soft cost (€/m$^2$) | Increased renovation cost (€/m$^2$) | Water efficiency cost (€/m$^2$) | Total cost (€/m$^2$) |
|---|---|---|---|---|---|---|---|---|---|---|
| #1 | 2345 | 1 | 194 | 123 | 30 | 18 | 9 | 11 | 1 | 387 |
| #2 | 5190 | 1 | 195 | 130 | 30 | 25 | 8 | 11 | 1 | 401 |
| #3 | 3300 | 1 | 179 | 146 | 30 | 30 | 9 | 12 | 1 | 408 |
| #4 | 2805 | 1 | 264 | 129 | 30 | 0 | 10 | 13 | 1 | 448 |
| #5 | 1144 | 2 | 311 | 152 | 30 | 17 | 13 | 14 | 2 | 541 |
| #6 | 6019 | 1 | 224 | 142 | 43 | 21 | 9 | 14 | 1 | 455 |
| #7 | 688 | 4 | 369 | 234 | 43 | 21 | 16 | 14 | 2 | 703 |
| #8 | 1124 | 2 | 162 | 133 | 30 | 27 | 11 | 11 | 2 | 378 |
| #9 | 714 | 4 | 427 | 158 | 30 | 52 | 20 | 20 | 2 | 713 |
| #10 | 1144 | 2 | 266 | 162 | 30 | 41 | 14 | 15 | 2 | 532 |
| #11 | 1833 | 1 | 315 | 168 | 21 | 33 | 13 | 16 | 2 | 569 |
| #12 | 876 | 3 | 316 | 168 | 21 | 33 | 16 | 16 | 2 | 575 |
| #13 | 773 | 3 | 344 | 155 | 30 | 35 | 17 | 17 | 2 | 603 |
| #14 | 2882 | 1 | 359 | 188 | 38 | 45 | 14 | 19 | 1 | 665 |

As far as an increased renovation cost is concerned, the main incremental cost component of LEED® certified buildings is the cost to green the building. The elements of these costs vary as widely as the LEED® certification criteria. They may include additional site work and structures; additional infrastructure costs related to transportation; recycling services at the site and sourcing specific construction materials (regional, recycled content, or certified forests). Based on data from the study [31] an increased cost equating to 3% of the renovation cost was used. Finally, the costs of water efficiency are related to the installation of flow reducers water (which were not previously present) and double-flow for the toilets in all school buildings. Considering the entire building stock, the average total cost required is 483 €/m$^2$.

As can be noted from Figure 3, the cost of building envelope retrofit is the highest cost item with 53.2% of total cost, heating systems retrofit is the second largest cost item with 29.7% of total cost (the total cost of building envelope and heating systems retrofit is 82.9% of total cost).

**Figure 3.** Incidence of cost items expressed as a percentage of total costs.



### *4.3. Critical Issues on Improving Sustainability in Public Schools in Italy*

One of the goals of this study was to identify any critical issues that may arise on improving sustainability for school buildings which are public assets (in our case the owner is the municipality), according to the LEED® procedure. The analysis of critical issues can be conducted by analysing three aspects: namely technical, administrative and economic.

The application of the LEED® protocol has not led to particular problems: the rules contained in the manual are clear and described in detail. Some difficulties have emerged during the collection of technical documentation: the lack of complete drawings, or the difficulty in raising them, resulted in a greater commitment during the survey through supplementary measurements. The collection of data related to energy consumption is not as simple as energy suppliers do not provide energy bills based on a standard format: the data must be processed in order to obtain a homogeneous profile of real consumption of energy. These difficulties, of course, should not be attributed to the LEED® procedure but the audit phase that is independent of the certification procedure choice.

From the administrative point of view, one must highlight the differences between the requirements in LEED® and the rules contained in the Building Code of the municipality. In particular this is important where the pre-requisites are concerned. A municipality that intends to use the LEED standard should conduct a review of consistency between the two instruments. The choice of the LEED protocol must nevertheless be a political choice for the municipality. The question you might ask when and regions have already adopted other protocols environmental certification (is not the case of the Lombardy Region).

The economic aspects are perhaps the most critical ones. Energy renovation does in any case require significant investments. In Italian school buildings it has been apparent that in some geographical areas priorities lie in seismic and hydro-geological safety. In our work we have only considered the costs related to sustainability performance but in reality we ought to add those necessary to guarantee safety. In some situations it could be cheaper to build a new building.

Another critical aspect relates to the cost of the certification. Who pays for the LEED certification, and who pays for the maintenance of certification in the subsequent years? In order to overcome the afore-mentioned weaknesses, we suggest a path of possible actions:

- Municipal administration should take the lead in actively promoting LEED® certification protocol for the benefits that this choice.
- The pre-requisite of LEED® protocol should be carefully considered in the implementation phase of the energy and environmental tools, particularly the Building Code.
- Energy and sustainable planning tools should be consistent with the base LEED® rating; organisations that implement the redevelopment work in schools (e.g., companies, installation contractors, manufacturers, ESCOs), could be stimulate to achieving higher rating (silver, gold and platinum) by means of incentives.
- Since the GBC are non-profit associations open to external contributions, municipalities should consider the possibility of being an active part in defining the criteria (for example by participating in working groups), in all cases an agreement protocol between the local GBC and the local municipalities is advisable.
- For the municipalities the assumption of costs for the certification process is difficult and in some cases impossible; the cost should be paid by those who create jobs, and who owns the buildings, within a facilities management contract.

## 5. Conclusions

This paper proposes and discusses a study which provides a considerable improvement in the environmental quality of 14 school buildings located in Northern Italy: the objective is to ensure the requirements for LEED® certification. The analysis has highlighted several critical issues which concern on the one hand both the cost-effectiveness of significantly improving the energy performance and the sustainability of existing school buildings, but on the other hand also the relationship which exists between a public body, such as a municipality, owning the buildings and a private entity, here the GBC, which manages the certification process.

On the first point it is helpful to make some reflections. The redevelopment of existing buildings normally only affects the energy aspects that are considered a priority. Investments in energy efficiency have the advantage of generating an income, due to the saving of conventional energy sources, which can help to amortise the initial investment. The improvement of sustainability is compared with logic that goes beyond: the aim here is to improve the relationship between the school building and the environment, in the hope that the real estate market is able to apply a greater value to a more sustainable building. The motivations that drive the real estate market toward greater sustainability base their roots in a general culture that has been changing in recent years: if it were not so, protocols such as LEED® certification would not have found much success.

The economic issue remains, however, and is even greater when operating inside the public market, which is made up of public buildings such as schools. The question that arises is this: in the sector of public building retrofit strategies should be limited to an improvement of the energy performance or should aim to improve the sustainability? The purpose of this study was also to give a response to this question. Considering the feedback emerging from our research, which is based on concrete examples of school buildings subjected to GEA, we can state that is more appropriate aim to improve the sustainability. The technical and economic assessments carried out in 14 schools showed that the higher cost due to the improvement of sustainability represents a small portion of the total cost of retrofit.

Given that the increased spending is due to the portion of energy retrofits, when a building is under redevelopment we should look beyond. It is time to orientate strategies towards sustainability targets. This choice is particularly important for the school buildings for better comfort with a high indoor air quality contributes to improving the conditions for learning.

This research was also an interesting opportunity to field-test the LEED® certification process. The result was positive: the procedure is clear and complete, despite being born in a different context than Europe (the United States) its application is found to be sufficiently consistent with Italian standards. The critical issues, discussed in the previous section, can be resolved through greater involvement of the public administrations and a greater consistency between the rules contained in LEED® and Building Codes. In all cases, the availability of a standard like LEED®, which has an international matrix, is a good thing when you consider the complex issue of sustainability of buildings with a broader vision.

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## Conflicts of Interest

The authors declare no conflict of interest.

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