ENVIRONMENTAL QUALITY AND ENERGY EFFICIENCY: SUSTAINABLE SCHOOL BUILDINGS DESIGN STRATEGIES

A. BOERI & D. LONGO
University of Bologna, Department of Architecture and Territorial Planning, Faculty of Architecture 'Aldo Rossi', Cesena, Italy.

ABSTRACT
The design and construction qualities of buildings play a key role in limiting energy consumption, while ensuring proper comfort conditions. The existing school buildings stock is mainly characterized by a low level of architectural quality and of performance leading to a high consumption of energy and to an indoor microclimate below comfort level. School buildings play a dual role: on one hand, they have to ensure adequate technical and morphological standards to all spaces used by the students, and on the other, they have to effectively communicate the criteria of sustainable design that have been used for their construction. This paper proposes some innovative case studies projects, highlighting criteria, and strategies adopted in the design for spaces dedicated to children. The aim is to promote sustainable design and construction strategies that combine high levels of energy efficiency, performance standards, and environmental indoor quality, including innovative strategies to integrate the building and its related systems. Best practices can also effectively encourage experimentations and contribute to formulate sustainable construction strategies that should be widely adopted.
Keywords: energy efficiency, experimentation, quality, school design, sustainability.

1 INTRODUCTION

School buildings are a topic of research of significant importance as regards its social value and relevant quantity.

The regulatory requirements, which provide the application of high standards of performance, and the several research experiences so far carried out, highlight a field of particular interest, where the technical solutions adopted are often used as a reference in other construction sectors.

As regards the structure of school buildings, they are designed in different ways in relation to the age of users, the educational models adopted, and the availability of spaces and funds.

Many school buildings are considered the ideal case study for the experimental application of sustainable design strategies, since innovative construction criteria related to the site, orientation and in broad terms to the strategies of bioclimatic settlement can be applied.

Consequently, schools are no longer just functional housing, but they can be converted into spaces that actively contribute to educate on sustainability [1].

This subject implies a dual series of issues requiring a solution.

The first set of issues are related to criteria of functionality and concern the environmental, technical, and morphological suitability of the spaces, which must provide high levels of performance, as regards microclimatic and thermo-hygrometric aspects, as well as natural and artificial lighting and ecological materials ones.

The second set concerns the sustainability strategies the building has to communicate through the spaces, its use, and its performance levels. The objective is to promote a higher degree of environmental awareness among the end users (see Fig. 1).

To efficiently implement strategies of sustainable approach in school buildings, subject to a high level of collective use, the problems related to the strategies for their setting in the urban context are to be assessed. It is preferable to use areas already urbanized, even if abandoned, provided with suitable infrastructures, serviced by eco-friendly public transport, and pedestrian and cycle lanes; these

ISSN: 1743-7601 (paper format), ISSN: 1743-761X (online), http://journals.witpress.com
DOI: 10.2495/SDP-V8-N2-140-157

Figure 1: The open space is dedicated to the educational and free activities [2]; it is characterized by different materials, such as sand, wood, stone, and grass, and it is provided with furniture and children play area. Nursery school Ponzano, Treviso (IT), 2007, A. Campo Baeza. Photo by Marco Zanta.

areas should be also provided with protected greens to guarantee the permeability of the soil. The selection of materials to be used should have a limited content of embodied energy, and the design and construction solutions should be energy efficient.

2 CONSTRUCTION TECHNOLOGIES

The research for higher levels of sustainability in the anthropic transformations of the environment involves all construction sectors, responsible for about 40% of the total energy consumption in the EU. For this reason, the research for sustainable design and construction has identified school buildings as the ideal testing ground. At this stage, the application of the concept of sustainability has wider connotations than the ones linked to the health and safety aspects and to the materials eco-compatibility ones, since it involves the analysis of environmental impacts and performance level during the entire life cycle of the building and beyond [1].

Materials have been object of a continuous evolution cycle: modern ecological materials have little in common with the ones produced in the past in terms of composition, production, and processing. They are the result of innovative and computerized production processes, with carefully monitored processing stages: the certification of sustainability bears witness to the environmental compliance in terms of production cycle and of suitability of use.

The wide range of semi-finished and pre-assembled components today available on the market has changed the working site, where, once, the activities of production and processing were carried out to an area, where the main activities now carried out are the ones related to the simple assembly of components.

After all, the high performance levels required of components and systems mean that said components and systems need to be produced off-site and with industrialized and controlled methods [3]. The demand of high quality standards to provide better indoor conditions stimulates the production sector to test most advanced and flexible industrialized systems and components, with the aim of providing the best technical solutions, while limiting costs.

The process of industrialization of the building component in relation to the achievement of high levels of performance is well represented by the current methods of construction of buildings which structure is mainly of wood, almost totally produced in laboratories and simply assembled onsite in

Figure 2: Extension of the primary school in Mezzago (MB), Arch. A. Varisco. View of the south side of the nursery school. Built totally with a dry construction system, this school is an example of an industrialized building system of wood for which factory pre-assembled large elements were used. Such a solution allows an environmentally friendly management of the site, the differentiated collection of the processing waste and a significant reduction in the time of realization (30 days for the assembly of the entire dry part).

a very short time. As a matter of fact, these systems allow planning of the construction process with greater efficiency, to increase the precision of the assembly, to reduce the margins of error, to restrict time and contain costs of construction (see Fig. 2).

This process allows obtaining high technical characteristics of construction, especially in terms of energy efficiency, a high level of control on the materials applied, precision and efficiency during the installation stage. Contrary to common belief, the realization of the building components in specially dedicated places, rather than directly onsite, offers the most suitable conditions for ensuring the control of the quality of the product, the check of the certified performances, and a rational management of the construction process. Furthermore, it is more cost effective as waste recycling is easier and the quantity of waste is reduced. The sustainability of prefabricated technologies is also represented by the easy maintenance and ready replacement of the elements, especially in the instance of layered systems made of wood and steel and dry assembled, that allow the selective removal of single elements to be replaced, therefore favoring their recovery and recycling.

On site, the workers of the past, with low technical knowledge, who often related to the basic processing of components and to the layout of systems, are today replaced by skilled workers, capable of completing the installation of far more advanced systems and components.

Therefore, the new ecological approach is not just a simple return to the materials used in the past, but it's a journey toward a sustainable construction methodology that will result in significant innovations, even within the area of school buildings. Consequently, it would be appropriate to pursue, even in light of the recent developments in this sector, an ever-increasing awareness of the suitability of the technical means in relation to the goals, focusing on design choices that are deliberate and right.

As Mies van der Rohe stated 'Less is more', it is necessary to better employ all available resources, combining the lowest possible number of means with a reduction in energy consumption and improved environmental conditions.

The traditional architecture is paying great attention in this direction, since many solutions adopted have taken into consideration the relationship with the context and its bioclimatic characteristics, the distribution and construction criteria of the buildings to ensure favorable microclimatic conditions with a limited use of modern systems. It is felt that we need to further the awareness of modern technological solutions and make them widely available.

Many application experiences on the relationship between climate and building, aiming at allowing an adaptive use of the building capable of responding to the changes of external conditions, while preserving the best indoor comfort conditions, are based on this subject and develop it.

Sustainable architecture, characterized by a cycle balance that could reduce and in perspective zero the environmental impact, is necessary for rebalancing the condition of the environmental situation. Therefore, it is the entire building process, and not just the use of the final product, that is the building in itself, that should be made more sustainable [4].

3 ENERGY CONSUMPTION IN SCHOOLS

A significant parameter to be valued concerns the power consumption. Schools consume too much: the high energy consumption generally is due to low environmental quality, low insulation, use of no performed windows, presence of thermal bridges, and obsolete equipment. These buildings are not comfortable and consume too much both in terms of economic impact and the environmental point of view (as shown in Fig. 3).

A recent survey of 50 schools in the Veneto Region in Italy, realized with a method of fast audit has highlighted energy needs of 250–350 kWh/m^2y, with an average of 290 kWh/m^2y which may correspond about to 82 kWh/m^3y.

These data are significant: according to the Italian regional classifications and regulations, these buildings would be classified in the worst energy efficiency class. A school classified 'A' in Emilia Romagna, indeed, has an index of less than 8 kWh/m^3y: that is to say that it consumes only 10% of the average requirements of the tested schools [5].

The aim consists of improving performance levels of buildings, providing better conditions of use and consuming less. The reduction of energy consumption and the possibility to meet needs of comfort represent a shared goal. The risk is that the low energy consumption is obtained, at least in part, losing environmental quality, in terms of good perception and functionality of spaces. On the other hand, it's necessary to promote sustainable design and construction strategies that combine high levels of energy efficiency, high performance standards, and environmental indoor quality, through innovative strategies for integration of construction system and plants.

4 ENVIRONMENTAL SUSTAINABILITY ASSESSMENT

The environmental sustainability assess of school buildings is a difficult operation, especially if it involves the entire life cycle analysis (phases of production, transport, installation, construction, management, and demolition) and the environmental impact of site and building systems.

Multi-criteria evaluation systems can be applied, based on a compared analysis of significant parameters, to be eventually extended to the entire life cycle of the building. In this case it is important to consider the energy consumption, a factor integrated with a complex series of other ones. The relative weight of various parameters can be adapted to different specific conditions of application. The national Protocol Itaca is one of these system [6].

Leadership in Energy and Environmental Design (LEED), an internationally recognized green building certification system, providing verification that a building was designed and built using strategies intended to improve performance in metrics such as energy savings, water efficiency, CO_2 emissions reduction, improved indoor environmental quality, has developed a specific evaluation

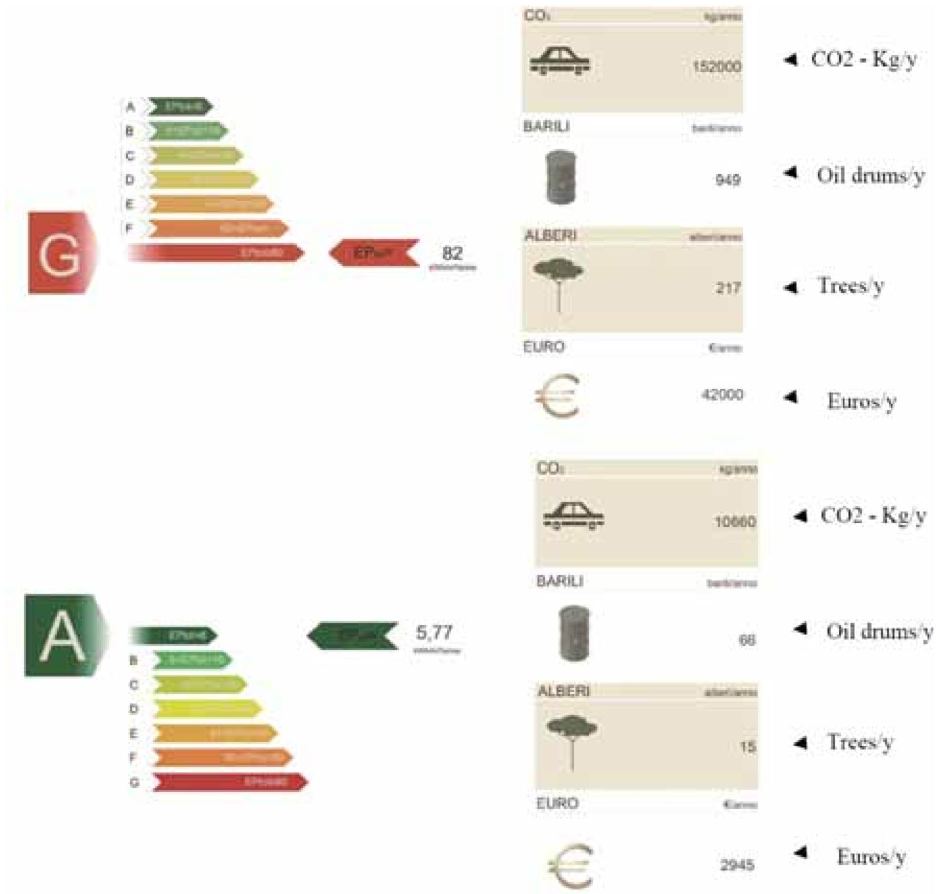

Figure 3: Comparison between the annual average consumption of a school of reference (EP_{tot} = 82 kWh/m³y), taken as an example of the average Italian situation, and the one of a building designed with the high performance envelope system (EP_{tot} = 5.77 kWh/m³y). Processing by Laboratory of Eco-Efficient Architecture, Faculty of Architecture, University of Bologna, AY 2008/2009. Coord. Prof. Andrea Boeri.

methodology for school buildings in United States and it has been wide spread in the world. It suggests a voluntary multi-criteria evaluation method of environmental and energy quality for sustainable energy efficient building development, with the aim of improving the quality and minimize environmental impact [7].

The rating system is based on specific credits, assigned for each requirement concerning sustainable aspects. Points are distributed across major credit categories. Their sum determines the overall score of building, and the level of certification is afforded. LEED certification is obtained after submitting an application documenting compliance with the requirements of the rating system as well as paying registration and certification fees. This system considers lots of parameters of sustainability, from the adoption of renewable energy sources to the choice of appropriate materials, local, renewable, recycled, ecologic with low emission of organic substances [8].

5 THE ENVELOPE SOLUTIONS

The building envelope is the outer layer that defines and protects the indoor environment and defines the architectural features. Through the envelope surface the relationships between the building and the surrounding context are established, and the exchange of light, air, heat, and noise between interior and exterior are controlled. The concept of the envelope as a barrier to the climatic conditions has been reconsidered in light of the goals of energy efficiency and consumption reduction: today the envelope is no longer considered as a separation element, but as an integrated and flexible system, that requires careful planning as regards the microclimate of the area and the multiple performances expected of the building, based on the different activities it houses and on changing climatic conditions it is exposed to.

It is important to consider the envelope as a dynamic baffle in the design stage of sustainable school buildings, which have to ensure strictly high level of performance in terms of indoor comfort, with a minimum use of systems integration (see Fig. 4).

During the last few years, an evolution has taken place as regards not only the clear and openable components of the building but also the solid ones: the monolithic morphological solution, where a single element provides all the basic performances, which has been gradually abandoned, in favor of multilayer solutions, where each element of the envelope plays different and complementary roles.

The concept of 'multi-layer membrane', for which all the components contribute to improve the performance quality of the envelope, cannot be separated from the evaluation of the eco-sustainability characteristics of the building materials to be used.

The reference standards are very detailed in defining the energy aspects for the architectural envelope and provide an effective tool for enabling to simulate, within an acceptable approx, all consumptions and to optimize the construction choices.

Figure 4: Kindergarten Ponticelli, Imola (BO), Arch. A. Contavalli. Southwest view of the Kindergarten. The south facade presents a glazed solar collector system, suitably shielded by adjustable wooden slats to prevent overheating during summer and to adjust the light let in.

In compliance with the European Directive that provides the minimum energy performance requirements to reduce buildings consumptions, our national legislation has reorganized the entire compartment. These provisions layout the criteria, the conditions, and the modalities to improve the buildings' energy performance to favor the development of renewable sources and energy diversification, limiting the gas emissions as provided by the Kyoto Protocol.

The modalities for computing the energy performance and the criteria for certification, used to verify the annual amount of energy actually used, or forecasted, are also provided to obtain the standards of quality and comfort expected. In particular, limit values of transmittance (U) for the envelope components and the annual primary energy requirements in relation to the climatic area and to the S/V ratio are identified (see Figs. 5, 6).

The energy performance index to be complied with, that is the primary energy consumption per surface unit or gross volume, and the values of thermal transmittance of solid structures and clear closures, are reported in the relevant tables, defined also in relation to the intended use. As far as schools are concerned, as well as for other class of buildings and for the purpose of limiting the energy requirements for air conditioning during summer and of controlling the indoor temperature, it is important to assess the efficiency of the shielding systems of the glassed surfaces and to check the value of the solid walls mass.

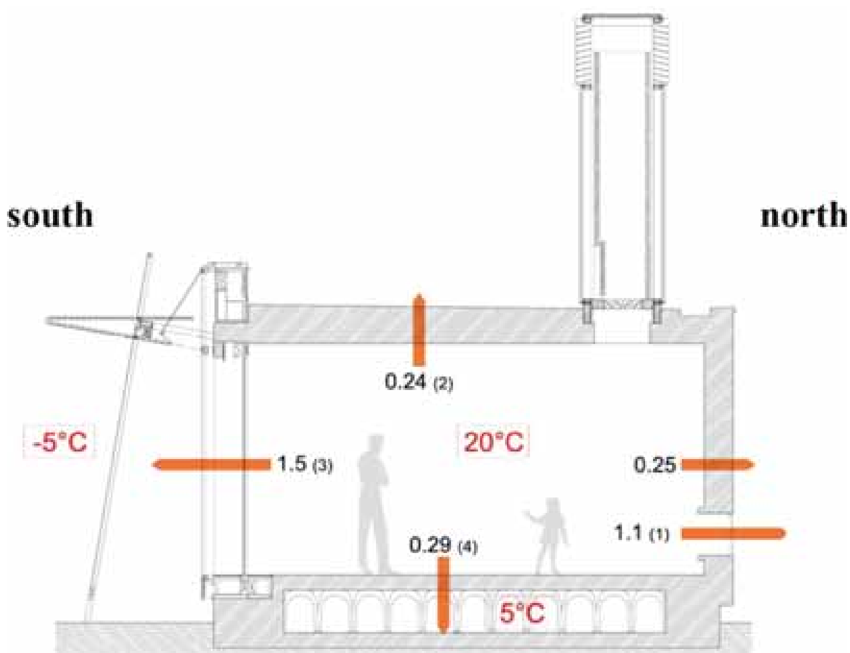

Figure 5: Kindergarten Ponticelli, Imola (BO), Arch. A. Contavalli. Scheme of the thermal transmittance of adopted in the envelope layers. (1) low-emissivity glass K = 1,1; (2) in correspondence of the beams K = 0,24; (3) indicative value: K was only for the inside glass section as, since the cavity is ventilated, the system is variable and K fluctuates within a range of about 0,4 and a maximum value of 1,5; (4) in case of floor heating K = 0,29. Processing by Contavalli Studio.

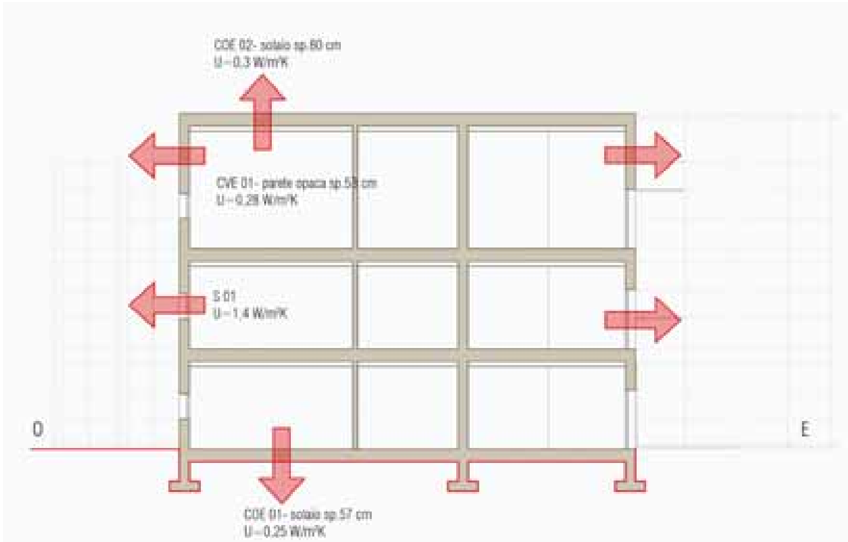

Figure 6: Synthesis of the transmittance values of the envelope system (solid and clear components). Processing by *Laboratory of Eco-Efficient Architecture.*

The recent guidelines on the matter of environmental protection establishing the use of breathable and hygroscopic elements, provided with characteristics capable of ensuring a good level of thermal, acoustic, and visual comfort, is in line with health and safety requirements.

The taken direction aims to ensure that a large portion of the indoor comfort conditions is achieved thanks to the characteristics of the envelope and of its components, using the systems as a support only during critical climatic situations.

For a school whose objective is sustainability and bioclimatic approach, it is necessary to carefully select the components of its envelope, so that they are suitable for its climatic context.

School buildings are usually used mainly during the winter months; however, the trend is to extend such period, using the building to host extra-school activities, even during the summer season. Consequently, the design of technological solutions must take into consideration a double set of needs: on one side, reducing heat losses during winter, by increasing the thermal insulation of the baffle elements, and on the other side, reducing the effects of solar irradiation during summer; for this reason, it would be best to shield the glass surfaces, providing solutions with high thermal inertia and using ventilated walls and roofs.

The use of green areas and of elements such as canopies, eaves, or rain roofs allows reduction of the excessive heat gains even in outside areas, providing playing areas for all season [3].

6 AIR AND VENTILATION

Children spend most of their time in school buildings: the presence of many people in an enclosed space leads to a quick decrease in air quality, due to a concentration of pollutants. To improve the users well-being, it is fundamental to ensure a proper indoor ventilation, favoring the necessary air change through an intake of fresh clean air and the ejection of the exhausted inside air (see Fig. 7).

In a school building, where the main purpose is learning and the developing of intellectual activities, air pollution is one of the main causes for a decrease in the level of attention paid by the users.

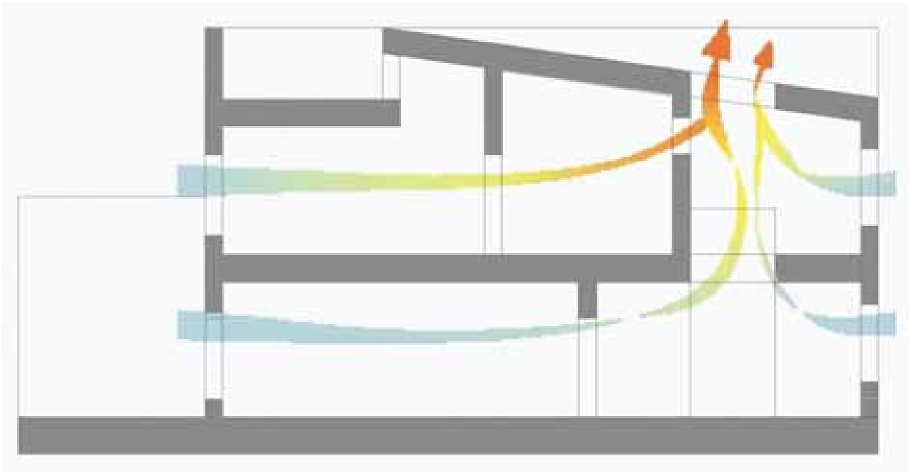

Figure 7: Natural ventilation through the building. The opening of window allows natural ventilation during the summer nights and during the autumn and spring period. Processing by *Laboratory of Eco-Efficient Architecture.*

Therefore, a good ventilation is essential to remove the sources of pollution and to maintain a high level of indoor comfort [4].

When many people stay assembled in anyone place, the level of humidity in the air tends to increase: the most commonly used parameter is the relative humidity one, which indicates the quantity of vapor content in the air in relation to the quantity it should be at a certain temperature.

As regards school buildings, it is advisable to maintain a relative humidity around 45–55% and this value could be reached by opening the windows to let in fresh and drier air during winter, or by a process of humidification of outdoor air carried out by a ventilation system.

Today the minimum standard of air quality is provided in Italy by the provisions established in the Decree of 18/12/1975, which are integrated with the guidelines laid out in the technical standards. This non-mandatory rule finds its main reference, at European level, in the standard EN 13779.

The approach of these regulations aims at controlling the concentration of pollutants, the percentage of humidity and the indoor temperature and at identifying the required volumes of air change, in relation to the type of building and to the activities carried out. In Italy, the mild weather conditions allow the fulfilling of these requirements through the opening of windows during the greater part of a year; however, in extreme conditions, in the middle of winter or summer, this would imply a waste of a considerable amount of energy. Ensuring a suitable ventilation of the enclosed spaces and restricting the energy consumptions of buildings is, therefore, a contradiction in terms. During winter, as a matter of fact, when we eject polluted air, we also eject the energy used to heat it and the clean air taken in from outside cools the environment, requiring a further consumption of energy to maintain the level of indoor comfort. The same happens during summer, when the hot and humid air taken in from the outside implies a greater use of air conditioning and a decrease in indoor comfort.

Based on the substantial quantity of air that needs to be changed to ensure the best indoor comfort, school buildings – whose objectives are high level of energy efficiency – must be provided with mechanical ventilation systems equipped with efficient heat recovery units. This solution, coupled with a careful sealing of all joints and all possible openings where air could flow through, allows to control the air flows and to drastically reduce energy consumptions.

An efficient ventilation requires a careful planning of the positioning and of the size of all openings, taking into account the particular conditions of the site, such as the strength and the main direction of the wind. To ensure a natural ventilation, the presence of openings on the two opposite sides of an room is a pre-requisite for a quick air change and for a generation of cross-flows. In this instance, the intake openings inlets are located at a lower level and can be of a smaller size than the outlet ones, usually located in a higher position. Ventilation, either natural or mechanical, can also be used as a cooling system during summer, useful for removing, during the night, part of the heat accumulated by the building elements during the day [9].

7 SITE AND OPEN SPACES

During the design stage of a sustainable school building, the identification of the site plays a fundamental role to limit the negative impacts of an unsuitable location, while highlighting the recourses in the context.

As indicated by the protocols for the assessment of sustainability, the choice should be carried out in advance, in relation to the potentials offered by the site, while looking for methods to safeguard the green areas and the natural resources.

Based on these aspects, special attention should be paid to the study of the allocation of the open spaces, to try and maximize solar gain and to optimize the orientation of the most used spaces [10]. Green areas play a fundamental role in education as they contribute to develop the perceptive capacities and the curiosity of students as well as to increase their wellbeing. For these reasons, it is important to provide green spaces of suitable size, visually connected with the inside and capable of offering a level of total security (as shown in Fig. 8).

Figure 8: The inside courtyard is designed as a place of social interaction between students. The open space was designed as an integration of the enclosed space and it is an extension of it. It ensures a bioclimatic relation with the inside environment and the physical and mental wellbeing of the children. Primary school in Ponzano Veneto (TV), 2008–2009, C + S Associates. Photo by Alessandra Bello.

8 FUNCTIONAL ORGANIZATION AND QUALITY OF SPACES

During the stage of the design of a sustainable school building, distribution and functional choices are also important, as their objectives is the configuration of pleasant spaces, suitable for the demands of the young users, who will spend most of their day there.

In the definition of the architectural choices, children and the activities they carry out play a central role, since the spaces of the school must meet the psycho-biological needs, favoring as far as possible the development of their personal capacities and of their learning (see Fig. 9).

All schools house a variety of activities and situations that take place in different spaces and environments: for this reason, the simplicity of the plant distribution, based on simple models of aggregation, is a basic requirement for an efficient organization.

The assessment of the correct orientation of the building, a rational and flexible use of spaces, the study of interiors design and finishings, of the relations with the green areas and the outside environment are the main themes to consider during the different stages of design, to favor educational activities and to achieve indoor quality [11].

9 NATURAL LIGHT

Inside lighting greatly affects the achievement of high levels of environmental quality and of energy efficiency in a school building [9].

The requirement of visual comfort must be taken into consideration from the very early stages of design, since it depends on the choices of functional organization and also on the architectural aspect, especially as regards the volumes, size, and location of openings and the presence of solar control systems. To ensure the correct execution of the teaching activities, the MD of 18/12/75 identifies the optimal values of inside lighting in relation to the type of space: 300 lux at the blackboard level, 200 lux on the school desks, and 100 lux in the corridors. Refer Figs. 10, 11.

In a sustainable building, these values must be achieved by using the available natural light in greater part and by using artificial sources only when strictly necessary, since both in the energy

Figure 9: One of the 'piazza' of the school Lama Sud in Ravenna. The quality of indoor environments was one of the prerequisite of the project. Here the different sections meet, turning into focal points around which students interact. The distinctive roof of the school is noticeable as well as the mixed wood–steel trusses. Photo by Spa Holzbau.

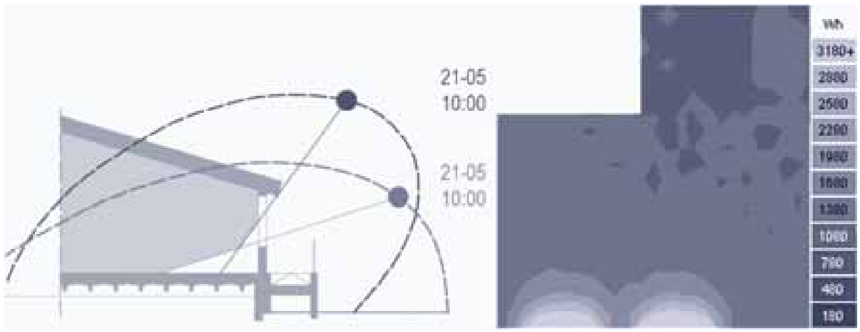

Figure 10: The verification of light comfort with predictive tools allows finalizing the architectural choices from the very early stages of the project. Analysis of a current situation in a school building: $R_i = 0{,}054$ ($<R_{i\ min} = 0{,}125$), Average Lux = 164 ($<Lux_{min} = 300$).

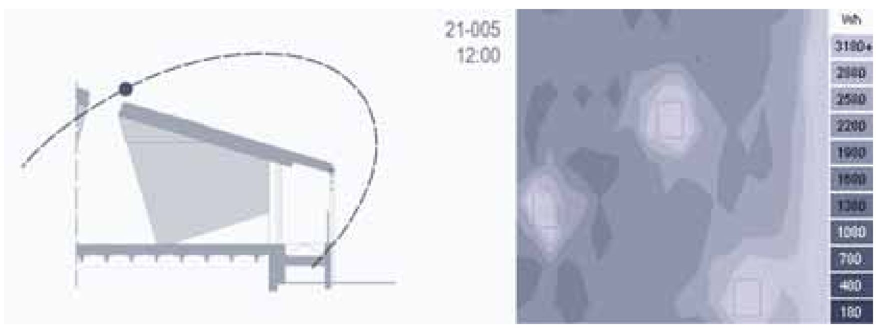

Figure 11: Project solution. Thanks to a newly designed roof light and to an extension of glazed surface, the results are: $R_i = 0{,}24$ ($>R_{i\ min} = 0{,}125$), Average Lux = 342 ($>Lux_{min} = 300$). The preliminary assessment with software allows to check the indoor lux level and to act on design strategies to achieve the objectives set by law.

budget of a school building the consumptions resulting from the use of lighting systems are an item of relevant impact and for the irreplaceable effects the available natural light produces in terms of indoor comfort [1].

10 ENERGY STRATEGIES

Today the most effective solutions combine passive working elements with active ones, aiming to integrate thermal and electromechanical devices with the architectural components.

To limit energy consumption and operating costs, it is essential to assure insulation of the envelope, adopting systems that use renewable resources, selecting the most suitable sources on the basis of geographical and climatic conditions: further to the solar energy, the geothermal one also finds every increasing application, while the wind power system is still not so widespread.

Based on the partial use of school buildings, significant reductions in consumptions can be achieved through the application of automatic control systems that provide structure to adapt the devices regulation in relation to the environmental conditions and to the users' needs [12].

11 SOME PROJECTS

Among the different aspects that need to be addressed to develop efficient solutions through all the stages of the process of design, realization, and management of a sustainable school, some themes of particular interest for the designer are highlighted. The choice of the site, the study of architectural and distributional quality of the buildings, and the assessment of design solutions, energy strategies and of environmental quality are reported in the following projects, which constitute an example of some of the possible strategies to apply.

These projects are the result of a research carried out within the Final Workshop: Sustainable Architecture – Technologies for Sustainable Design (coord. prof. A. Boeri), Faculty of Architecture of Cesena (University of Bologna) [1].

11.1 Nursery school in the district of 'Osservanza' (Cesena, Italy)

This project consisted in a nursery school with four sections that currently represents a model of environmental sustainability and quality of use.

Its layout is characterized by a series of spaces placed along a straight path, similar to a road, where the children gradually come into contact with the different areas of the school. The main functions of the school are organized around its central axis: these areas are housed within singular and independent volumes, incorporated in a modular system. The setting of the project based on modular elements has contributed to obtain a good compact volume (S/V = 0.66) and a good sun exposure.

The planning and functional organization of the spaces is a result of the correct orientation of the building in relation to solar radiation. It has a central distribution plan that ensures an exclusive outside area to each pedagogical unit, with a good exposure to the south. All sections have solid walls facing north and a large glassed surface facing south, allowing an optimal level of interior lighting, opening outward, with a view of the surrounding hilly landscape. The sections are connected to the outside area through a greenhouse, acting as a filter-zone between interiors and exteriors, that can be opened when necessary; these greenhouses have a positive impact on the building bioclimatic behavior and allow a greater level of indoor comfort: during winter, they are closed volumes where the air is preheated before being inlet, while, in summer, they can be totally opened, to allow their all-round ventilation and therefore avoid overheating (see Fig. 12).

11.1.1 Technologies

The building presents a mixed technological system, that is to say that it alternates walls realized with a dry system (U = 0,14 W/m²K), consisting of a wooden framework with a layer of insulating material, and wet walls (U = 0,17 W/m²K), which, due to their high mass, allow to limit the energy needs for air conditioning during summer and to keep the indoor temperature constant, thereby improving the level of indoor comfort. All thermal-break windows (U = 1,32 W/m²K) are realized with wood-aluminum frames, double-glazed and with a low emissivity, to significantly reduce energy consumption and CO_2 emissions. An extensive green roofing (U = 0.19 W/m²K) covers the entrance, while a ventilated one, with a sloping angle of 19° to favor ventilation and avoid the problem of overheating in summer (U = 0,21 W/m²K), covers the classrooms and the common space.

11.1.2 Systems

In this project, the sustainability approach also concerns the use of renewable sources and the choice of systems, which have to meet the need to assure a healthy indoor environment and a reduction of energy consumption. Heating is provided by a floor heating system, associated to a natural-gas-fired

Figure 12: During summer, the greenhouse is completely disassembled and a system of adjustable slats protects the classroom against overheating. The greenhouse, closed during winter, allow taking advantage of the passive heat gains resulting from the solar radiation on the glass surfaces. *Laboratory of Eco-Efficient Architecture*, Faculty of Architecture, University of Bologna, A.Y. 2008/09. Coord. prof. Andrea Boeri. Processing by F. Dalla Casa.

condensing boiler, and by a solar power system placed on the roof. The natural ventilation system is integrated with a mechanical one to guarantee the required air changes. Each section is provided with a heat recovery unit for the ejection of exhausted air.

11.1.3 Energy saving

Due to the design choices and the selection of high performance components, the school building obtains an energy certification of 'Class A' of the Emilia Romagna Region (Italy), with a consumption equal to 5.36 kWh/m³/year. In conclusion, this building achieved not only significant cost savings, but also low CO_2 emissions, equivalent to 7.84 kg/year/m^2 (see Fig. 13).

11.2 A school complex in Bertinoro (FC, Italy): energy-functional requalification and expansion of the secondary school 'P. Amaducci'

This project dealt with the subject of efficiency and functional requalification of the secondary school 'P. Amaducci' in Bertinoro and with the construction of a primary school, within this same area, which shares the areas for after-school activities and sports with the pre-existing one.

The existing secondary school 'P. Amaducci', built in 1990, is a building of about 17,800 m^3, with a plan characterized by an open courtyard; it develops on three floors, on the east side of which a building block of 12,000 m^3 was built in 2000, housing a sports center. Even if of recent construction, this structure presents several design deficiencies, including the unfavorable orientation of the classrooms, the low energy performance (the building is in an energy class F), and the general

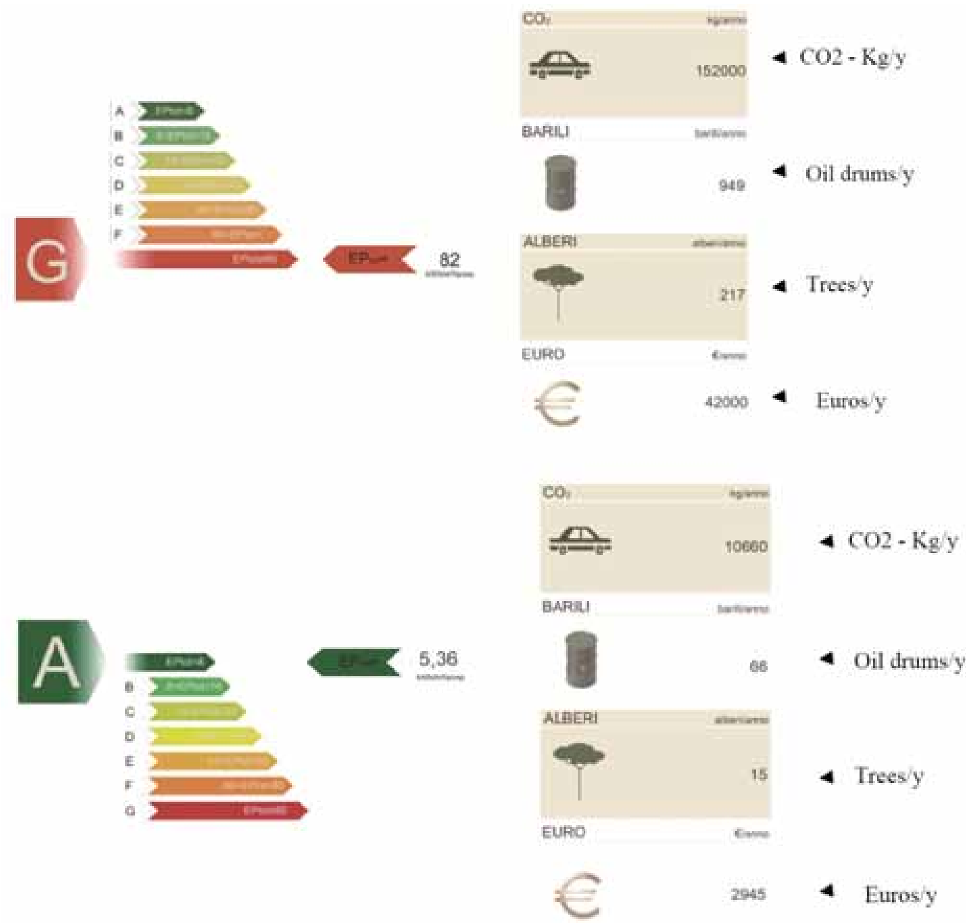

Figure 13: Comparison between the consumption of an Italian school of reference with the ones of the project. From 82 kWh/m³/y to a forecasted consumption of 5.36 kWh/m³/y. Processing by *Laboratory of Eco-Efficient Architecture*.

over-sizing of the complex (180% of space more than the one provided by the M. D. of 1975 on the matter of school buildings) (see Fig. 14).

The design strategies proposed based themselves on the public administration requests, asking for a very detailed functional program. This project envisaged the construction of two interconnected school buildings, with a requalification of the existing building and the construction of a new block. Common spaces were designated for extra-school and sports activities (see Fig. 15).

The strategies for the requalification of the existing structure included:

- the study of a favorable orientation for the classroom (relocated from the north to the southeast side);
- the study of a high performance envelope, characterized by green roofs, extensive clear surfaces on the south side (shaded with screen panels) to obtain high solar gains during winter, and by more opaque surfaces on the north side to avoid excessive heat losses;

Figure 14: An external view of the current school. Photo by S. Ugolini.

Figure 15: A rendering of the project. Processing by S. Ugolini.

- the improvement of systems, due to the application of heat pumps and of a controlled mechanical ventilation system, with consequent significant reduction of the building energy consumption;
- the integration with renewable sources (a solar panel system integrated with the shed roof).

With these interventions the school building would be classified within the energy class A, according to the classification of the Emilia-Romagna region (see Table 1).

11.2.1 Technologies

The existing reinforced concrete structure is integrated with a dry system in wood, through the application of bearing walls in X-LAM. This system is also used for the realization of the roof and the shed, supported by the existing portals of reinforced concrete.

The building envelope is totally replaced with one of higher performance. The existing glazed surfaces, facing north-west, are replaced with a light and ventilated system having a wooden structure, insulated with 20 cm of rock wool, covered with laminated panels and small windows, therefore, obtaining a transmittance of 0.17 W/m²K. On the south-east side, the wall realized with blocks of concrete is replaced with a lightweight façade with structure in wood and aluminum. This façade is largely glazed, screened by solar shading elements, with a transmittance of 0.21 W/m²K.

Table 1: A comparison between the current status and the requalification intervention.

Current status	Re-qualified school complex
Gross heated volume: 17,850 m³	Gross heated volume: 12,080 m³ (extension of the new primary school excluded)
Total usable surface: 4,050 m²	Total usable surface: 2,400 m²
Envelope dissipating surface: 5,500 m²	Envelope dissipating surface: 4,400 m²
S/V: 0.31	S/V: 0.36
EP = 61.64 kWh/m³y	EP = 4.75 kWh/m³y (a reduction of energy consumption of 92% when compared to the current status)
Energy Efficiency Class: F	Energy Efficiency Class: A
Primary energy requirements for heating: 1,076,000 kWh/year	Primary energy requirements for heating: 57,380 kWh/year
Primary energy requirements for hot water production: 23,857.30 kWh/year	Primary energy requirements for hot water production: 15,208.20kWh/year
Envelope transmittance: well above the required standards	Envelope transmittance: about 30–40% less than the standards limits
U roof: 1.35 W/m²K	U roof: 0.20 W/m²K (extensive green roof): about 33% less than the standards limits (0.30 W/m^2K)
U wall 1.41 W/m²K	U wall: 0.17 W/ m²K (ventilated façade with rock wool insulation, thickness = 16 cm): about 50% less than the standards limits (0.34 W/m^2K)
U windows: 2.05 W/m²K	U windows: 1.30 W/m²K (light façade with wood and aluminum risers and openable windows) : about 33% less than the standards limits (2.20 W/m^2K)
U ground floor: 1.50 W/m²K	U ground floor: 1.50 W/m²K
Energy costs per child: 382 EUR/year	Energy costs per child: 31 EUR/year
Equivalent emissions of CO_2 per child: 2,031 kg/year	Equivalent emissions of CO_2 per child: 148 kg/year

The project foresees a green roof (transmittance equal to 0.20 W/m²K) and a top layer of gravel (transmittance equal to 0.19 W/m²K); the ground floor is preserved in its current state.

11.2.2 Systems

Subsequent to the improvements to the envelope, the next step consists in the replacement of the E-generation system with a heat pump and a heat recovery system, providing for both the winter heating and summer conditioning needs, with consequent costs and energy savings. Finally, the plant system is to be integrated with the installation of renewable sources: a PV and solar system on the roof, consisting in 132 multi-crystalline silicon photovoltaic panels.

11.2.3 Energy saving

Use of renewable, recycling and environmentally friendly materials, the energy efficiency of the envelope, green roofs, the study of an optimal shape, and right orientation of the facades: these design choices are all oriented toward environmental sustainability.

In particular, the study of an envelope with high performance, characterized by large glazed surfaces, facing south to obtain the maximum solar gain in winter and appropriately screened in summer, and by opaque surfaces on the north side to avoid heat losses, the systems improvements, the integration with the photovoltaic system, placed on the roof, contribute to a significant reduction in energy consumption, allowing to achieve the energy class A, with an index of final $E_p = 4.75$ kWh/m³y.

12 CONCLUSION

The researches and projects presented in this paper also demonstrate how a correct design of school buildings can meet the comfort requirements.

These experiences aim at integrating sustainability, spatial and perceptual quality with energy efficiency needs. The architectural and formal features, the proper positioning of the building in the lot, its correct orientation, the selection of the most suitable construction systems and materials contribute to reduce the use of installed systems, which should be only considered as an integrated support to the architecture, with substantial benefits in terms of resources and energy saving.

Highly comfortable and pleasant spaces, homely and inspiring, in buildings with a distinctive 'character', with a recognizable identity and high standards of sustainability, can positively contribute to the formation of public spirit and environmental awareness of their users and of the local communities they are located in. [1, 2].

REFERENCES

[1] Antonini, E. & Boeri, A., *Progettare scuole sostenibili. Criteri, esempi e soluzioni per l'efficienza energetica e la qualità ambientale.* Edicom: Monfalcone, 2011.
[2] Hertzberger, H., *Space and Learning*, 010 Publishers: Rotterdam, 2008.
[3] Boeri, A., *Strategie sostenibili per l'edilizia scolastica. Efficienza energetica e qualità ambientale,* in *Integrare per costruire*, SAIE 2010 – Cuore Mostra I Seminari, BolognaFiere, Be-ma, Milano, pp. 1–26, 2010.
[4] Boeri, A., "Criteri di progettazione ambientale – Tecnologie per edifici a basso consumo energetico", ISBN 978-88-89518-35-9, Editoriale Delfino, Milano, 2007.
[5] Ecosistema scuola 2011, available at www.legambiente.it
[6] Boeri, A. & Longo, D., Learn to save: sustainable schools. *Energy and Sustainability III*, ed. V. Villacampa, C.A. Brebbia & A.A. Mammoli., Wessex Institute of Technology (UK), ISBN 978-1-84564-508-3, WIT Press, pp.425–436, 2011.
[7] United States Green Building Council, *Foundations of the Leadership in Energy and Environmental Design, Environmental Rating System, A Tool for Market Transformation*, 2006, August.
[8] U.S. Green Building Council, available at www.greenschoolbuildings.org
[9] Il portale dell'edilizia di qualità, available at www.qualitaedilizia.it
[10] Canizares, G.A., *Kindergartens schools and playgrounds*, LOFT Publications: Barcellona, 2008.
[11] Poletti, L., *Spazi abitativi per bambini*, Libreria Clup: Milano, 2002.
[12] Passive House Institute: available at www.passivehouse.com