Chapter 48
Energetic and Functional Upgrading of School Buildings

Paolo Giordani, Alessandro Righi, Tiziano Dalla Mora, Mauro Frate, Fabio Peron, and Piercarlo Romagnoni

Abstract In Italy, currently most schools require improvements to energy performance and indoor air quality. On the other hand, school buildings require structural assessment and strong renovation interventions to maintain their service functionality. Moreover, the use of spaces should be reviewed and redesigned to be more compatible with modern educational models, making the schools unique integrated spaces. Each space should have the same dignity and flexibility, meeting anticipated future needs and expectations and offering a positive environment that should support learning, teaching and recreational activities. The national government has recently launched policies and plans to face up to this situation, imposing some guidelines to incentivise the actions of local municipalities. The challenge as well as the aim of this research is to verify the possibility of combining energy retrofits with functional renovations as a unique approach to taking action, exploring the conditions and measures to create synergy. As a case study, school buildings in a medium-sized city, Castelfranco Veneto, in the north-eastern part of Italy were analyzed with the aim of defining a method of intervention on different functional layouts. In a first phase of the work, all 21 schools present in the area were analyzed. Subsequently, three groups of buildings with homogeneous characteristics in terms of age, construction technologies, and shape factors were identified. Finally, a case study for each group was analyzed in detail and a proposal for improvements to the energy efficiency and functionality was presented. In this chapter, one of the case studies is presented.

P. Giordani • A. Righi • T.D. Mora (✉) • M. Frate • F. Peron • P. Romagnoni
Università IUAV di Venezia, Venice, Italy
e-mail: tdallamora@iuav.it

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1 Introduction

In present-day Italy school buildings assets are characterised by high levels of energy consumption and inadequate levels of spatial comfort. This research aims to outline a methodology that can be used to assess a series of measures targeted at the improvement of both energetic performances and spatial distribution of this enormous heritage of building stock. In recent years, sustainable policies extensively funded by the Italian government and the European community have facilitated the process, aimed at the improvement of the energetic efficiency of school buildings. However, the rearrangement of their spatial and functional characters has often been left behind.

In March 2013 the Italian Ministry of Education, University, and Research (MIUR) published a document containing guidelines regulating the technical design details of the school building stock [1]. This issue has led to the transformation of school buildings into civic centers, a connection with the urban fabric, where, thanks to a renewed concept of space, frontal lessons are no longer considered the leading model in pedagogy [2, 3].

Indeed, the objective of research in this area has become the creation of a strong synergy between those two aspects of the intervention in order to come up with integrated design solutions – improving both energetic performance of buildings and the quality of space, resulting in a better teaching environment.

2 Methodology

2.1 Analysis of Existing Stock

In Italy, the existing school building stock is composed mainly of buildings constructed from the first post-war period to the 1980s. Moreover, historical buildings, built between 1750 and 1900 and readapted for educational activity, represent a smaller part. Therefore, these buildings rarely have the directives of administrative order D.M. 18/12/1975 on school buildings imposed on them [4]. As a whole, the Italian school building stock reveals a generally low level of attention in terms of energy efficiency, low levels of maintenance of different components and finally a not always correct use by users. They do not use the most profitable types of energy, or their production and distribution systems result in low output; energy is not used in the most efficient manner – for example, some buildings are characterised by a high level of heat loss, while other spaces are overheated. In all these scenarios energy use is inefficient, resulting in negative effects on the comfort of users and in the waste of resources.

These buildings are overall characterised by energetically inadequate envelopes and systems, where the comfort and quality of both air and spaces are often at a low level. Moreover, the environmental conditions hamper the learning process and the work of teachers. To analyse quickly and simply this vast network of buildings, a simplified methodology has been put in place. This technique permits the evaluation of energetic performance with different levels of accuracy.

First, a precise analysis of a sample of buildings must be carried out. This analysis must be accomplished using a database containing information about the age, technology, volume, usage time, spatial distribution and energetic consumption records of buildings.

Second, the buildings are divided into homogeneous groups composed of elements with similar characteristics. The parameters used to accomplish this division are construction period, shape factor and volume of the construction. The construction period identifies the available technology and the materials used, the presence of insulation and the rigidity of the functional layout. The shape factor identifies the shape of the building and serves as a valuable indicator of the level of dispersion of heat through opaque envelopes: buildings with a high shape/volume (S/V) index show greater dispersion through the covering horizontal structure; buildings with a low S/V index show greater dispersion through walls. The volume of construction is also important because it affects the level of energy consumption: the efficiency of improvements grows in proportion to the level of energy consumption of the building. After these considerations, three different groups were selected: historical buildings with low S/V and low volume, non-historical buildings with low S/V and high volume, non-historical buildings with high S/V and low volume. The grouping into homogeneous types of buildings allows for the optimisation of punctual analysis of a specimen of construction aimed at the projection of individual results to all buildings with the same typology.

2.2 Evaluation of Energetic Performance

Together with the homogeneous grouping of existing school real estate, it is also necessary to precisely evaluate the energetic performance. Using a simplified evaluation index, it is possible to have an energetic framework of a sample, identifying criticalities and average values for each homogeneous group. The evaluation method employed is the one proposed by the ENEA-Fire methodology [5]. This methodology consists in the estimation of a Normalised Energetic heating Index (IENr). This normalised index takes into account some sensible factors like the amount of hours in which the heating system is turned on and the shape factor (S/V), derived with the ratio of the dispersion area of the construction shell (S) and the relative heated volume (V). The IENr index allows for a first evaluation of the energetic behaviour in the heating season of each building-plant system. This results in an ultimate grouping of the typologies with respect to the level of education: for example, primary school, secondary school and high school. The IENr takes into account actual energy consumption (C), heated volume (V) and the location of the edifice (degree day, GG). It is then normalised through two different indexes: shape factor (Fe) and the number of hours the heating system is activated (Fh):

$$\mathrm{IENr} = \frac{C \times \mathrm{Fe} \times \mathrm{Fh} \times 1000}{V \times \mathrm{GG}}.$$

To ensure the quality of the evaluation, as indicated in the preceding discussion, it is advisable to overestimate the IENr index by 10 % so as to take into account eventual areas in which the temperature does not register at a constant 20 °C. Considering both the IENr and the level in the Italian school system, the energetic behaviour of the building-heating system complex is evaluated and grouped into three different classes: good, sufficient and insufficient behaviour.

Following a raw analysis it is possible to analyse in detail the energetic behaviour of a sample of buildings representative of a specific homogeneous class. This analysis is given by the conversion of all information about the constructions into a mathematical model and its energetic simulation in a dynamic regime, calculated using certain software. The mathematical model is created integrating data obtained from previous analysis and other data acquired through the methodology presented in the standard UNI TS 11300 (parts 1 and 2) [6, 7]. The energy analysis of the buildings was performed using the EnergyPlus [8] simulation tool. To improve the quality of the evaluation, the numerical model is calibrated with the data on real consumption.

After the construction and calibration of the numerical model, a direct and precise evaluation is developed towards more advantageous and profitable operations. The results of the various proposed improvements to operations are evaluated through a comparison of performance indices concerning energetic consumption, reduction of emitted CO_2, annual economic savings and time of economic return.

2.3 *Project Proposal*

In accordance with the MIUR guidelines [1], various design proposals were analysed in order to ensure the coexistence of energy-efficiency-improvement measures with the functional improvement. These operations will give new spatiality and new teaching functionalities to buildings. Owing to the low modifiability of the spatial-functional structure of the Italian school building stock, mostly because of their outdated construction, the application of these guidelines has proved to be very difficult; in addition, the guidelines were conceived with new constructions in mind. Various project solutions have been proposed to apply these directives to already existing Italian school buildings (Fig. 48.1). These solutions are not invasive and assure the maximum functional output.

(a) The action on internal partitions – usually made on the basis of a division between classrooms and hallways – makes it possible in the connection space

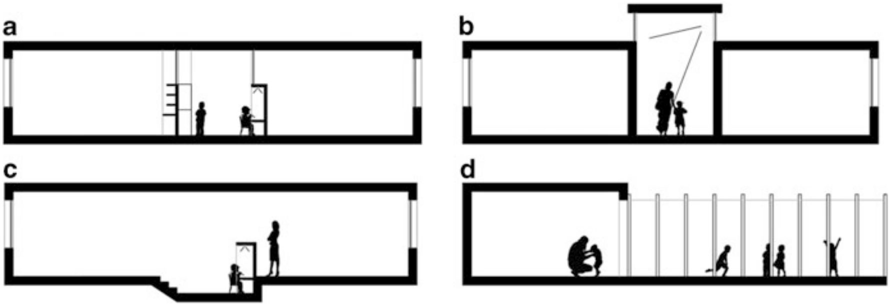

Fig. 48.1 Functional measures schema: (**a**) on internal partitions, (**b**) on upper horizontal partitions, (**c**) on lower horizontal partitions, (**d**) on external partitions

to define a system of small recesses and spaces for individual study and small student group activities, resulting from the integration of properly equipped walls.

(b) Operations on upper horizontal partitions are particularly useful as a support to the creation of new teaching spaces since they allow natural light, which promotes well-being, comfort and energy savings in spaces with little lighting, for example, hallways.

(c) Intervention on lower horizontal partitions, if possible, is extremely effective, especially thanks to the creation of different paving quotas. This action will define diversified spaces in the same space which will assure adequate levels of privacy for specific activities because of visual obstacles.

(d) Action on the external partitions of buildings is generally applied to buildings with a single floor which open out onto external gardens where possible. Classrooms are designed with the exterior space in mind thanks to the opening of glass panels and pergola systems which serve both as a protection from atmospheric agents and as spaces for outdoor teaching activities.

3 Application

3.1 Case Study: San Andrea Primary School

This section presents an application of the methodology previously described. The case study is a school building property in the municipality of Castelfranco Veneto (TV). The municipality owns 21 school buildings of different levels (e.g. kindergarten, primary and secondary) and aims to develop an intervention strategy targeted at all buildings. The proposed methodology is a tool supporting the Castelfranco Veneto municipality for identifying the most suitable interventions.

The analysed school was identified from the application of the methodology. In fact, 21 schools were analysed in terms of energy performance and then divided into homogeneous groups.

The elementary school San Andrea is a primary school in the village of San Andrea oltre il Muson, located in the south-west of Castelfranco Veneto. The building dates back to the early 1960s and is characterised by a floor above ground and by a small portion on the first floor. The building is constructed of brick masonry without insulation. The pitched roof is made of a slab of masonry covered by a simple blanket of clay roof tiles supported by warping boards and planks of wood. The window frames were replaced in 2007 and are in good condition, but they do not meet the most current standards in terms of energy efficiency. The windows are composed of a metal frame without a thermal break and of a simple double-glazing unit with air. The heating system dates back to the building construction, but in 2007 the old generator was replaced with a condensing boiler of 105 kW which offers good performance, though it is limited by the old system of distribution, control and emission.

Regarding spatiality and space distribution, San Andrea school is an emblematic case and presents characteristics common to the majority of other primary schools built in the 1960s and 1980s. The centrality of the classroom and, therefore, frontal lessons have always been considered the hub of learning.

The school has a functional area of 1236.5 m^2, of which:

- 259.5 m^2 (21 %) is used for the classrooms;
- 373.4 m^2 (30.2 %) is used to support teaching (laboratories, library and gym);
- 319.0 m^2 (25.8 %) is used as service areas (toilet, kitchen, boiler room); and
- 284.4 m^2 (23 %) is used as connection spaces (distributive).

A preliminary analysis shows that teaching spaces (the first two items) have an area almost equivalent to the areas of service and connection (last two items). In these terms the design choice has been to carry out a revaluation of the distributive spaces, which now look like simple corridors which are mostly dark and used only for connection purposes, in order to identify eclectic and multifunctional spaces which can at least partly meet the new functional requirements (see Sect. 1.1.3 of the MIUR guidelines).

3.2 Energetic Improvement Measures

The analysis of the San Andrea school was also supported by an assessment of the dynamic numerical model of the building which was aligned with the actual energy consumption of the school. This allowed us to analyse the energy performance of the building, quantifying the heat loss through the building envelope: 8 % of losses are through glass components, 10 % through walls, 2.5 % through floors, 26.5 % through the coverage (roof), 20 % through infiltration and 33 % from natural ventilation. These data identified two critical issues: dispersion through coverings

Table 48.1 Improvement measures

Measure	Consumption [kWh/a]	Savings [%]	Cost of intervention [€]
Actuality	90,865.25	–	–
Roof insulation	74,856.51	**17.62**	45,584.26
Wall insulation	80,160.58	**11.78**	114,750.31
Window replacement	87,803.13	**3.37**	50,906.35
Heating system generator replacement	87,419.41	**3.79**	13,645.85
Wall insulation + roof	63,404.14	**30.22**	154,437.94

and heat loss due to natural ventilation, which, however, is necessary to ensure the correct ventilation of the spaces.

Then improvements more appropriate to the situation were identified and analysed (Table 48.1). The most advantageous strategy identified was to intervene by insulating either the outer walls or covering in order to reduce the energy consumption of the building by 30.22 %. Note that in this building, consisting mostly of one floor and with a very high form factor, the single best intervention is to insulate the covering because this results in a reduction in energy consumption of 17.62 %. The costs of the intervention were obtained from the official price database of the Veneto region [9].

3.3 *Design for Increasing Functionality*

Following the definition of necessary improvements for energy performance, a design strategy was formulated to improve the use and usability of the space.

Because of the rigidity of the internal structure of the school, it is not possible to make radical changes to the space distribution, but some specific actions could be taken in line with the policy of energy conservation (Fig. 48.2).

The first proposal is to drill the floor ceiling and roof in order to ensure an adequate level of natural lighting and air exchange in the corridor below. The second proposed action is to replace the internal vertical partitions, placed as separators between educational spaces and the hallways, with a system of walls which can accommodate both the side facing the classrooms and laboratories and the side facing the distribution spaces. Storage spaces will be placed near the entrances: in the classrooms for learning materials for the students, in line with the concept of ‘school without a backpack’, and close to the access of the building for materials intended for particular activities. On the sides of these storage spaces, the walls will house in the lower parts a system of recesses for study or individual reading. In the upper parts (above 1.80 m), to ensure adequate visual impediments, some glazed surfaces will be placed between the spaces: in synergy with skylights these must eliminate the feeling of extreme isolation created by the earlier corridor.

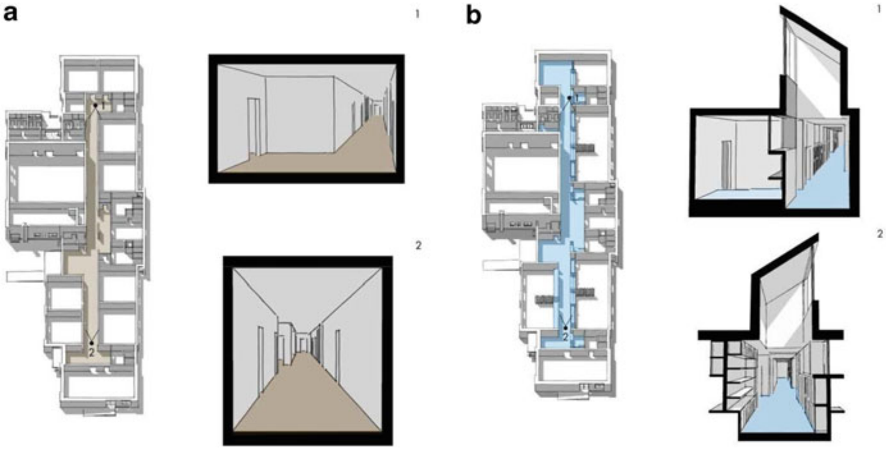

Fig. 48.2 (**a**) Current situation. (**b**) Possible intervention of project design

Finally, other spaces obtained from the recess of the corridor near the entrance to the bathrooms have been redefined as informal spaces for relaxing, with the addition of paving and soft seats suitable for this purpose.

4 Results and Discussion

The definition of interventions on various buildings, according to a division into homogeneous groups, allows a more complete view through the identification of parametric costs in €/m^3 based on detailed metric calculations, which quantify the cost for retrofitting existing school buildings (Table 48.2). Every parametric cost refers to the best intervention among all options in the same category in order to obtain 20 % annual savings in energy consumption.

For example, in the S. Andrea case study, 30.22 % of annual savings is derived from 110.83 €/m^3 total parametric cost; the energetic solution combines two interventions – covering insulation (point of greater criticality) and external wall insulation – in order to ensure adequate performance by the elimination of thermal bridges, giving a parametric cost of 42.71 €/m^3. As regards intervention for increasing functionality, the solution adopted concerns the conversion of the large space of the central connection into a so-called learning street capable of accommodating various educational activities through the use of skylights, movable and foruiture and facility, giving a 53.09 €/m^3 of parametric cost.

The best relation between costs and benefits belongs to the group of nonhistoric buildings with low form factors because the large volumes lead to targeted interventions, mostly by the insulation of walls. With regard to nonhistoric buildings with high form factors, the most efficient intervention is insulation cover. Historic

Table 48.2 Cost-benefit relation

Group of buildings	Energy efficiency parametric cost (€/m^3)	Functional improvement parametric cost (€/m^3)	Total parametric cost (€/m^3)	Annual savings (%)
Historic buildings $S/V < 0.70$	50.08	42.18	92.26	25.72
Nonhistoric buildings $S/V < 0.70$	43.53	37.60	81.13	38.25
Nonhistoricbuildings $S/V > 0.70$	43.13	45.68	88.81	35.9
Total	44.54	43.23	87.77	34.9

buildings present a low cost-benefit ratio because the construction technique is outdated, the system net is very rigid and the space is not suitable for school activities. The most significant intervention in these cases appears to be improving the heating system, glazing systems and, sometimes, the lowering of too high ceilings.

5 Conclusions

The values, even if indicative, outline a credible scenario and show how to improve the existing school building stock, and not necessarily requiring high expenditures, but supported in part by incentives – eschewing radical actions which might be more effective but much more expensive and less feasible due to lower investments in the school system.

Several problems have been encountered in the research stages: in the initial data collection period, simulations of the mathematical model, especially the estimated period of natural ventilation inside rooms, and then, during the planning stage, the application of solutions to space-functional distribution into very rigid and not very changeable structures.

The results show the possible interventions on school buildings and their cost-effectiveness, but the main result is the elaboration of an experimental method that offers the best design of rational, sustainable and cost-effective measures to improve the existing buildings, regardless of the geographical context and or type of building analysed.

Research efforts could be directed at studying how this methodology would be replicated on different scales and in different types of existing buildings. For other schools with different uses and different levels (high schools, universities) can be verified by assessing patterns of energy consumption and the proposals of design interventions dedicated instead, in the case of schools in different climate zones, energetic intervention and architectonic design will be based on the setting and social climate. For other types of buildings, public or private, with different uses (commercial, residential, office), the methodology will be fully adequate, with particular attention paid to the evaluation of energy performance, energy design and functionality.

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