Energy retrofit and indoor environmental requalification of existing school buildings. Method and tools for operating procedures

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Abstract: Within the existing building stock, schools occupy a large segment of public real estate but are rarely involved in widespread retrofit investment plans. For example, according to Italian statistics, two thirds of existing schools are hosted in buildings constructed between 1940 and 1990, many of which have not undergone substantial changes and transformations over time. Verifications made by Public Administrations and users demonstrate that these structures have many building problems related to the consumption of resources, the well-being and security of users and, not least, the management by local government units.
Operating substantially and in a scheduled way on existing school buildings, by adapting the physical environment and optimizing the use of resources, would, on the one hand, increase the quality of construction and conditions of use (and then last but not least the effectiveness of the educational system) and, on the other hand, improve the economic management of resources by local government units.

Keywords: *Existing educational buildings, Energy retrofit technologies, Indoor climate enhancement, Operating procedures.*

1. Introduction

Within the Italian existing building stock, schools occupy a large segment of public real estate (throughout the country there are about 42,000 schools). Schools host a very sensitive group, but currently don't provide the necessary well-being and use a large amount of resources. Nonetheless, they are rarely involved in widespread investment projects of national interest. The national annual reports provided by Legambiente [1] show that about 1 out of 3 buildings needs urgent maintenance because of many problems related to resource consumption, indoor environmental quality, security conditions and management by Public Administrations.

The present paper presents the results of a syudy aimed at establishing planned, systematic, substantial and integrated operating procedures for energy retrofit and indoor environmental quality enhancement on existing school buildings to increase construction quality, reduce energy consumptions and optimize economic management of resources by the Owner. Even if this topic has already been developed on the international landscape (IEA ECBCS Annexe 36 [2] is one of the most important experience), it hasn't found a pragmatic approach yet in Italy where, because of the low qualification of the public technical staff and of the few economical investments by the Owners, it is (and even more will be in the next few years) a real problem for Public Administrations from the economical, management and security points of view.

2. Methodology and phases

Given that the Ministry of Education or Local Goverments do not provide any comprehensive technological database concerning building elements and plant systems, it has been decided to directly investigate an existing school building stock by studying a sample of buildings that has been considered to be representative of the wider national situation (different climatic conditions, various building technologies and plant systems, different energy contracts and management). The survey procedure has been essential to define energy benchmarks and technological state of the art that has been compared with best practice projects, choosen from national and international landscape and concerning exemplary and innovative requalification processes on existing school buildings. The direct results of the study sample survey have been compared with the performance requirements coming from national regualtions and lows that are considered to be the minimum level of success of the future retrofit strategies. Retrofit measures has been defined through: energy and environmental goals (from the previous survey and best practice analysis), needs-performance framework (from low and regulations) and best technical solutions for energy and quality enhancement (referring to the outcome state of the art of the surveyed study sample).

The operating procedure has been systematically developed to support decision-makers during the retrofit strategy choice, considering performance targets, technological (energy saving and environmental quality enhancement) and economical (payback period optimization) aspects, people involved (technical staff, Owners, Designers, Energy Managers) and in order to obtain an appropriate management of the existing school building stock.

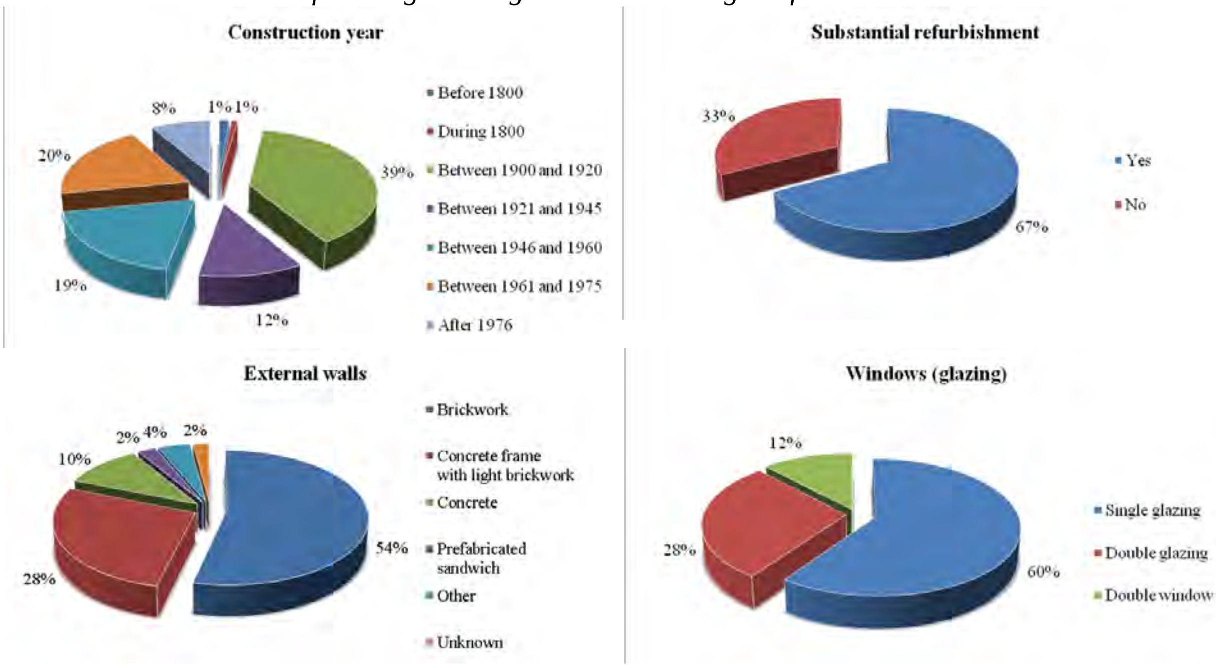
3. State of the art: the technological point of view

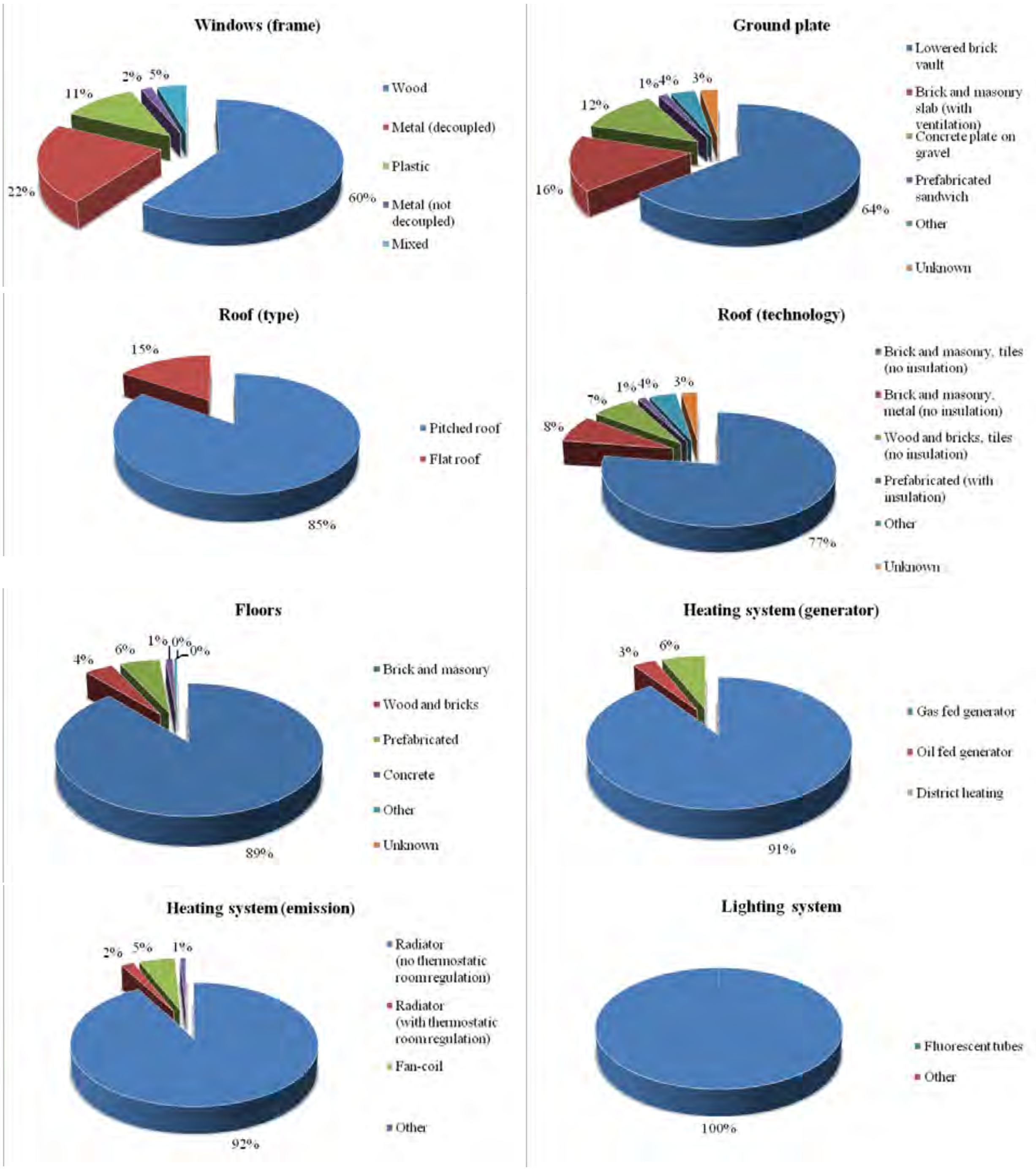
The study sample has focussed on the municipalities and provinces of Rovigo, Ferrara and Modena and has been composed of 232 buildings. The abovementioned municipalities and provinces have been chosen because of the information available and their geographical location, in a temperate area requiring more attention in the building and plant system design. The survey shows that existing school buildings of the study sample are in a critical situation.

Table 1 List and geographical distribution of the study sample.

Municipality or Provincial Administration	Number of investigated buildings
Municipality of Ferrara	53
Province of Ferrara	27
Municipality of Rovigo	25
Province of Rovigo	24
Municipality of Modena	69
Province of Modena	34
Total	232

Table 2 Overview results of existing buildings actual technological features.





3.1. Building envelope

From an energy point of view, heat losses through the building envelope are mainly due to the lack of thermal insulation in walls, roofs and ground floors. Traditionally, Italian constructions have a strong brick enclosure, which can be single layered or combined with other materials (concrete blocks, plaster, stone and wood), and whose performance is particularly poor in buildings dating from the Fifties and Seventies.

Even windows and glazed systems have a very low performance. This aspect is particularly relevant because school buildings have many large window areas in order to archieve lighting targets. The study sample also has a low proportion of low-emissivity glass (most of the buildings are single-glazed) and frames, which are primarily wooden but without seals, or metal but not thermally decoupled. Importantly, however, windows replacement is the owner's first item of intervention.

3.2. Heating system

Investigated school buildings have traditional heating plant systems (consisting of boilers which are mainly powered by natural gas) with no zoning. The output terminals in classrooms are large radiators, mostly made by cast iron, which, with rare exceptions, don't have any thermostatic control valves or any room regulation. Because of the amount of air to be heated, mechanical ventilation systems (without any heat recovery) or plants heaters (fan-coils) are often used in larger rooms (gymnasiums, lecture halls, laboratories). The employment of air heating system (air vents) is much more limited in classrooms, because of noise transmission, air movement and filter maintenance. Mechanical ventilation systems are also rarely used and are almost completely absent in the existing school buildings which have been evaluated.

3.3. Summer air conditioning system

Since school buildings are used in Italy from September to June, air conditioning systems are quite rare and the study sample has confirmed this trend. The only exceptions to be found are school staff offices where low-performance and high-consumption independent air conditioning units which are not connected to the centralized system have been installed.

3.4. Lighting system

The investigation demonstrated that schools are only lightened by fluorescent tubes without any occupancy sensor (for example in hallways or bathrooms) or automatic dimming of light intensity according to the amount and distribution of natural light in classrooms.
Beside the absence of energy saving devices, a comprehensive design based on different lighting needs in classrooms (especially to avoid glare and to promote a homogeneous distribution of natural light) and in other parts of school buildings is also lacking.

3.5. Energy sources

Natural gas is currently the most widely used energy source, but few buildings still use diesel. Usually, these are isolated buildings located in the outskirts of cities and villages which are not yet served by the distribution network because of local conditions. A good practice is the connection to the district heating network, but it is still incomplete and quite limited in some areas. Renewable energy sources (mainly photovoltaic and solar thermal) have begun to be used only in recent years, particularly in structures with continuous use and extra-curricular functions.

4. The operating procedure: application phases

Enery and environmental analysis of the study sample direct survey data have demonstrate how existing educational buildings are distant from the minimum performance requirements given by lows and how uncomfortable many scool buildings are for occupants. The operating procedure minimum level of success is the archievement of the minimum performance values given by national lows and regulations for the parameters that are responsible of considerable variations of energy consumption and environmental quality (air, temperature, humidity, lighting, noise). The further level of success is the archievement of the maximum level of energy saving and indoor environmental quality enhancement (increasing comfort perceived by occupants), together with the optimization of the Owner's economical investment.

Therefore, the operating procedure deals with several topics (technology, energy, economy, management, etc.) which are considered in subsequent and linked phases and should be seen as a decision support tool for recovery strategies of existing educational buildings.

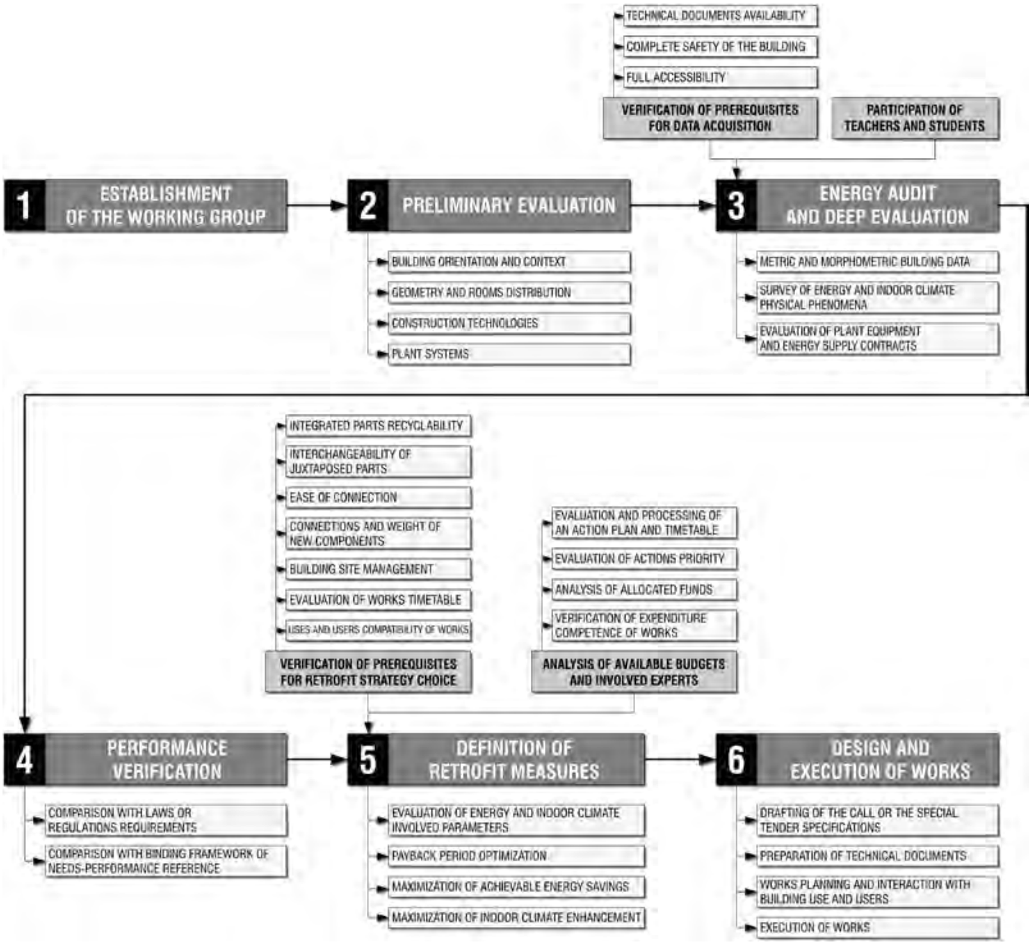


Fig. 1 Operating scheme of energy and indoor environmental refurbishment process.

4.1. Step 1: establishment of the working group

The first step of the procedure is the establishment of a working group composed of people involved in the management, design and educational process. At this stage, several stakeholders meet the Public Agency that promotes the intervention, which ca be the municipality or the province depending on the specific competences on the school building stock; the Educational Institution, that has the double task of informing about the critical problems related to the use and to initiate educational activities to raise awareness among students (for example, daily actions aimed at savings and at the management of energy resources); the Designer, who is tasked with drawing up the project and coordinating the activity; and the Energy Manager, who optimizes energy management in different building redevelopment stages.

4.2. Step 2: preliminary evaluation

The second phase is a preliminary evaluation of the existing building, aimed at identifying morphological features and general technologies which are useful to define the retrofit strategy to be adopted. In particular, the following aspects must be evaluated:

- building orientation and evaluation of the surrounding natural or urban elements that may affect energy and environmental behaviour (shading from adjacent buildings that limit solar direct gains, proximity to noise sources, presence of vegetation shielding, etc.);

- building type (geometry) and internal distribution of rooms. This can be done by reading the project plans with their subsequent modifications and implementations. This information is aimed at finding a first guidance for action based on the savings potential inherent in any type of building;
- existing construction technologies of technical element. Information in this regards can be retrieved in the project documentation submitted during the execution of works (if any), in owner's and manager's databases or through a direct visual examination;
- plants systems. This can be studied basing on the direct experience of Energy Managers or through visual inspection of books and equipment (in this case, the potential for savings depends not only on the optimization of the plant system, but also on the verification of the supply contracts, especially in the context of energy market liberalization).

The most critical part of this phase is the definition of the technological features, due to owner's or managers' lack of knowledge about construction techniques and plants systems of the building heritage. Public Administrations do not usually have any monitoring tools to manage the building stock and leave the transmission of information to the "historical memory" of the contractors carrying out maintenance.

4.3. Step 3: energy audit and deep evaluation

This phase may require external professional support to evaluate parameters that affect energy and environmental building behaviour. There are three main subtasks:

- determination of metric and morphometric building data for calculation of gross floor areas, heated volume and dispersant surface, aimed at energy evaluations;
- survey of physical phenomena related to energy and environmental building behaviour concerning the whole technological system (enclosures and internal partitions), by studying the main factors affecting energy consumption and indoor comfort (air, temperature, humidity, lighting, noise);
- evaluation of plant equipment and energy supply contracts (which may cause consumption not attributable to the efficiency of plant system).

Since this phase requires where direct investigations on the building several conditions must be met to be able to gather data, such as:

- full accessibility to different parts of the building, including basement, attics and spaces normally closed to the public;
- guarantee of the complete safety of the building;
- availability of technical original and subsequent versions of design documents, as a basis for the determination of the status quo.

4.4. Step 4: performance verification

The fourth phase, which is closely linked to the previous one, is a comparison between measured performance and laws or regulations requirements in relation to the parameters involved in energy consumption and indoor environmental quality. By comparing the actual performance and with the binding framework of needs-performance reference for each building element, the main critical elementsd of the existing building are identified.

4.5. Step 5: definition of retrofit measures

The people involved are the same as in the preliminary working group but the Designer is definitely the emerging personality. He is tasked with coordinating the different needs and defining technically and morphologically relevant design solutions.

Before planning any activity, the presence of some prerequisites has to be verified, as:

- compatibility of works with building uses and users;

- evaluation of the works execution timetable and its relationship with school activities;
- management of building sites (possibility of storage of materials, accessibility, etc.).
- connections and weight of the new components compared to existing structures;
- ease of connection of any new elements to existing structures;
- interchangeability of juxtaposed parts related to future opportunities for interventions;
- recyclability of integrated parts.

Apart from these considerations, the Designer shall, in collaboration with the Promoter, verify and analyze the available budget and experts involved through:

- a preliminary verification of expenditure competence of the works
- an analysis of the funds allocated by the local Administration or the Owner;
- the evaluation of the actions to be performed depending on the priority and urgency of interventions;
- the evaluation and development of an action plan accompanied by a timetable.

Once these steps are completed, the most appropriate intervention strategy can be chosen basing on the evaluation process (preliminary or in-depth), the issues raised during the performance evaluation (energy and environmental factors involved), the Owner's budget or investments availability and the main features of the building site. Given that these involved factor are several and complex, it has been decided in the study to define a panel of retrofit measures [3], aimed at finding the best technical solution for the specific case and based on the need-performance requirements. Therefore, the action to be identified are those which can optimize the payback period (expressed in years), maximize the energy savings (expressed by the percentage reduction of primary energy consumption compared with the previous condition) and enhance the environmental quality to the greater extent (expressed by an occupant's sensation scale from 0 – neutral to +2 – considerably perceived; action with negative influence on occupants' perceived comfort will not be taken into consideration).

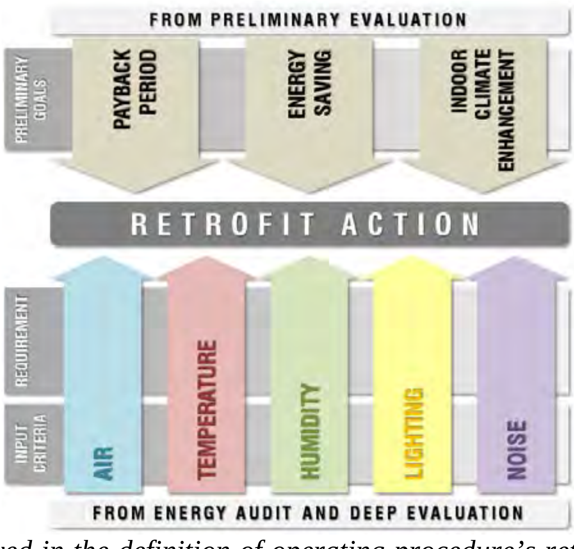


Fig. 2 Main criteria involved in the definition of operating procedure's retrofit actions, starting from preliminary or deep evaluation of existing educational building.

4.6. Step 6: design and execution of works

This phase includes the following:

- drafting of the call or of the special tender specifications;
- preparation of technical documents in collaboration with other experts and stakeholders involved (the document will be entirely drafted by the Administration in case of internal procedure, otherwise they will be contracted out to Designers);

- works planning taking possible interaction with building use and users into consideration;
- execution of works.

The drafting of the documents containing the technical specifications of the project and for the tender is the most critical point of this phase. This phase may be rather long because of the high number of experts to be involved and the unexpected prolongation of the timing of the tender. In addition, the organization of timing and of the different phases of the works, together with the potential overlapping with school activities, may lead to moving classes in other temporary structures, is another complex aspect in this phase.

5. Further suggestions

5.1. The potential of integrated and optimized procedures for morphometric and energy data collection on existing buildings

The current research in the field is even more focussed on the definition of integrated and optimized procedures for data gathering by integrating experimental acquisition methods and instruments (advanced survey). Consequently, proper planning and scheduling of all survey phases is crucial, with the aim of determining an optimized sequence of steps for acquisition, processing and management of data. Each phase is not independent and autonomous, but functional and closely related to the others. Thanks to technological innovation and economic competitiveness, the more advanced techniques are reaching levels that make them comparable with traditional ones, but with the addition of the features of the advanced survey, especially in terms of productivity because they significantly increase the amount of information gathered, reducing the time needed for the survey.

5.2. Importance of post occupancy evaluations and participatory management

Once works have been executed, it is essential to carry on with building management activities, i.e. all operation, maintenance and monitoring phases on the reskilled building aimed at comparing project design criteria to real performances obtained. They include:

- students awareness and training on how to use the building in a proper way in order not to waste energy that would result in a reduction of the achievable savings and, therefore, in the extension of the payback time.
- participatory management of the redeveloped building through the involvement of users;
- post-occupancy evaluation, also through the participation of users (even students and teachers) to data acquisition and monitoring of the building;
- periodic monitoring of contracts for energy management, consumption and counters, to be carried out by an Energy Manager.

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