TYPOLOGICAL AUDIT FOR ENERGY RETROFITTING OF EDUCATIONAL BUILDINGS

Richard Cantin and Gérard Guarracino[1]

ABSTRACT

In a context of reduction of greenhouse emissions and sustainable development, energy and environmental requirements, indicators or tools, are in ever-increasing numbers in the building sector. Moreover, decision makers and designers have to deal with the increasing complexity of analytical approaches to the retrofitting of educational buildings: numerous actors, independent objectives, different technologies and new systems, qualitative and quantitative data, together with economical, environmental and sociological constraints, and so on. Thus, efficient management of energy audits of educational buildings seems to take a long time and be extremely complex.

In order to improve the decision making process for the energy retrofitting of educational buildings, our aim was to identify specific typological features for implementation in the first steps of an energy audit.

First of all, complementary to the classical analytical approach, a systemic approach allowed us to identify and to model energy features of educational buildings. Then, a parametric approach was used with statistical and systemic data, and with a design tool for building performance simulation. In this way, several heuristic typological elements were defined which led to multidisciplinary approach to the energy performance of whole buildings.

In this paper, the context, specific issues and objectives related to the energy retrofitting of educational buildings are described. Then, we explain how a systemic approach allowed us to improve the analytical approach, in order to identify energy performance, with specific reference to educational buildings. In the last section, we present principles and results of this typological audit applied to a study of a stock of educational buildings in France.

KEY WORDS

building, retrofitting, typology, energy, audit

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INTRODUCTION

In the next years, an important stock of educational buildings must be retrofitted in France, for historical and demographic reasons. These retrofitting projects must be carried out in a context of reduction of greenhouse gas emissions and energy consumption.

Among different targets for retrofitting of educational building, the improvement of energy performance is a strong challenge for the decision makers in urban and civil engineering. Indeed, low energy consumption must be achieved with high and sustainable performances of indoor environment.

However, energy and environmental requirements, indicators or tools, are in ever-increasing numbers in the building sector. Moreover, decision makers and designers have to deal with the increasing complexity of analytical approaches to the retrofitting of educational buildings: numerous actors, independent objectives, different technologies and new systems, qualitative and quantitative data, together with economical, environmental and sociological constraints, and so on. Thus, efficient management of energy audits of educational buildings seems to take a long time and be extremely complex.

In order to improve knowledge of decision makers and for best results in retrofitting, we have studied audits for energy retrofitting of existing educational buildings, in Rhône Alpes area.

In this paper, the context, specific issues and objectives related to the audit for energy retrofitting of educational buildings are described. Then, we explain how a systemic approach allowed us to improve the analytical approach of an audit, in order to identify energy performance, with specific reference to educational buildings. In the last section, we present principles and results of a typological audit applied to a study of a stock of educational buildings in France.

SPECIFIC ISSUES FOR ENERGY RETROFITTING OF EDUCATIONAL BUILDINGS

SOCIAL AND HISTORICAL ASPECTS

In France, the heating surfaces of the stock of educational buildings represent about 140 millions m². On the one hand, the main political and local organization is involved in school responsibilities either for investments or operating budget. On the other hand, teachers and operational staff salaries and prerogatives are responsible to the central state (Laforgue, 1999)

Between 1880 and 1945, Jules Ferry, the public instruction and art minister, introduced the idea of "the school building" with a regulation concerning building construction and furnishing. School architectural basis is dictated with the air cubic content, airing and cleaning notions being specified.

After the second world war, until 1960, the population explosion induces the French institution to build new school buildings. In front of such quantitative constraints, new rational building processes are defined. Buildings become more linear and parallel.

Between 1960 and 1975, the school house idea does not still a topical question. New competitions are launched around the idea of a new design process consisting in taking into account the control and the adaptability. The building construction rate increases and reaches 350 educational buildings per year in 70's. In this period, three main tendencies can be observed: linear and long buildings with 3 or 4 levels, pool of 3 or 4 storied buildings around a more attractive life centre, and compact dimensions and various height, patio, and outdoor playing area (Laforgue, 1999).

Then, since 1975, the number of new building being constructed slows down due to the demography drop. Energy saving, and architectural quality are the main priorities (thermal insulation, blinds and solar protections, heating regulation and design, daylighting, and so on).

At present, the educational buildings from the 60's have to be retrofit with energy and environmental requirements.

CONSTRUCTIVE ASPECTS

Educational buildings have different age, size, volume and can contain various space types with different set-point temperatures and activities. For instance, one of these may have intermittent heating, including classrooms, libraries, offices, laboratories, dormitories, health care facilities, athletic facilities, auditoriums and others. This diversity of floor use creates both challenges and opportunities for implementing energy retrofitting projects of varying size and scope.

The architectural design and the indoor fittings were governed by the necessity to suit to an adapted scale to occupants and to look for a familiar environment. The school had to be integrated into its public environmental space taking into account the main characteristics of the neighborhood as well as the landscape and the topography in the frame of the school integration.

The range of materials used for a school building is representative of the school building design choice. It can be made in classical materials as brick, concrete, metal or stones as well as innovative material use. A large diversity of material, construction (structure, facade, glazed wall, insulation, etc.), heating, ventilation and air conditioning systems, or solar and lighting systems, creates various issues which are strains on maintenance staffs (Laforgue, 1999).

THERMAL ASPECTS

The building thermal design depends on four main parameters:

- the building site according to the climate conditions
- the building orientations in order to optimize solar gains
- the building compactness relative to the envelope area which is connected with the outdoor environment
- the walls insulation

Otherwise, the suitable equipments for school buildings use heating, ventilation and cooling techniques. The main techniques for the heat transmitting equipments are hot water radiators and convectors, electric convectors, basic heating floor completed with convectors, radiant heating (floor, ceiling, heating films), aerotherms (hot water or gas), radiant panels and fan-convectors.

The importance of heating gains due to occupants or other internal loads can induce a cooling requirement. Occupants are close together having four times as many occupants as office buildings for the same amount of floor space.

Natural ventilation through an outdoor opening, simple or double flow mechanical ventilation are commonly used in educational buildings

Thus, educational buildings have many specific aspects which should be considered in the design of retrofitting projects. At the opposite of a new building, an existing educational building already have existing geographical constraints (site, orientation, etc.) and a technical, economical, social, environmental and architectural history which gives a framework for retrofitting.

ENERGY AUDIT METHODS

The audit is a study of the analysis type with 3 main steps (Despretz, 2002):

- collection of data on the site and use of a calculation tool to simulate the energy consumption for all end uses.
- comparison with actual consumption.
- list of all energy conservation options.

At present, various audit methods are used to evaluate energy performance for educational buildings. An energy audit may cover a site or a building. The scope of audits may be narrow (one specific system or process) or wide (inside the site fence). The thoroughness of audits is directly related to the time and cost spent on the project. Energy audits are used for different purposes. The aim of audits may be either scanning the areas of possible energy savings or analyzing in detail the individual energy saving measures.

For instance, a walk through energy audit is a scanning model typically used in tertiary buildings where the energy consuming systems are quite simple, and the probable areas for potential energy saving measures are known in advance.

Otherwise, a system specific energy audit is an analyzing audit which covers only one system, device or process, and in practice ignores the rest of the building. An analyzing audit is in practice always started with a scanning type of action, but the difference is in the thoroughness of the auditing work.

Thus, various energy audits are used to evaluate energy performance of existing educational buildings (Brejon and al., 1988):

- Pre-diagnosis methods aim to classify improvement targets in descending order of probable importance, in terms of energy and financial savings. For instance, energy ratios (kWh/m².year, kWh/person, etc.) are used in order to assess this potential and the size of improvements to be undertaken.

- Explanatory methods used for prediction are based on models representing the building and its equipment, which is analytical. There are static methods and dynamics methods with different algorithms.
- Identification methods (for instance, energy signatures) consist in making an overall estimation of essential thermal specifications of a building and its HVAC equipments.
- Specialized diagnosis are studies of a building highlights the need to make an in-depth studies of a particular item (for instance, boilers and burners, damp and air renewal, etc.). They often require specific intrumentation.

However, because of specific aspects of educational buildings (some of these aspects have been given previously), several limits of each analytical audit method are identified:

- it isolates the building components and it concentrates on the elements. It does not unify the different components in whole approach of a building.
- it studies the nature of interactions between components more than the effects of interactions.
- it emphasizes the precision of detail, for instance, with specialized diagnosis, without a global perception.
- it remains independant of duration of time, without considering the irreversibility of historical aspects of existing educational buildings.
- it leads to retrofitting strategies programmed in detail more than through performance objectives for the building.

For these different reasons, a broad and complete audit of existing educational building is necessary before the retrofitting conception.

Indeed, the energy performance in retrofitting strategy has to be associated with the quality of the audit. An existing building is a complex system constituted through a large amount of non-linear interactions and cannot be separated from its environment. Thus, it is not possible, in practice and in principle, to give a complete, analytical and formal description of an existing educational building. We have to frame the system in a certain way when we want to describe it. We objectively cannot determine the limits of our description or our audit. However, various studies showed that measurements of energy savings, combined with an improvement of indoor air quality, are rarely applied in retrofitting, because of a lack of knowledge of decision makers concerning the quality of a complex audit (Cantin and al., 2004).

With a systemic approach, we identify structural and functional aspects of existing educational buildings. The structural aspects concerns the organization in space of the components or elements of a system (Rosnay, 1975). The functional aspect concerns the phenomena dependent on time. Thus, in this way, specific aspects about spatial and temporal organization allow the study of types of existing buildings (BRECSU, 1997):

- design approach: auditors should ensure an integrated design approach. The correct balance must be maintained between educational and energy issues. It is important to ensure that new and existing equipments are compatible to achieve a good performance. The impact of each retrofitting measure on each other, and on the occupants, must be carefully assessed. Furthermore, the density of occupancy is much higher in educational buildings than in other types of buildings.

- site and plan form: it can provide opportunities for energy efficiency and improvements in the amenity of local environment. Orientation and passive solar strategies must be considered in the energy audit.
- construction and building fabric: construction, insulation, ventilation, windows and glazing have to be considered because of their impact on the thermal performance.
- services: for instance, space heating, domestic hot water, control systems, lighting have to minimise distribution and production energy losses.

Thus, several structural and functional parameters can be considered in order to define a typological energy audit. For instance, there are design approach, occupancy, site and plan form, heating space, envelope, energy sources, age of building.

TYPOLOGICAL AUDIT

In this way, we have investigated a systemic approach in order to provide principles and results of a typological audit. We have studied a stock of educational buildings in Rhone Alpes Area in France.

The study is based on a panel of more 70 educational buildings. These panel data allow to identify main parameters to take into account for a typological audit. Moreover, the schools may be categorized according to a typology framework for schools (Annex 36, 2004): the village school, the multi-storey school, the central corridor school, the side corridor school, the pavillon school, the main hall school, etc.

The panel of existing educational buildings allowed to identify a design approach with six main plan forms: rectangular (R), square (C), L-shape (L), U-shape (U), H-shape (H), and school with patio (P).

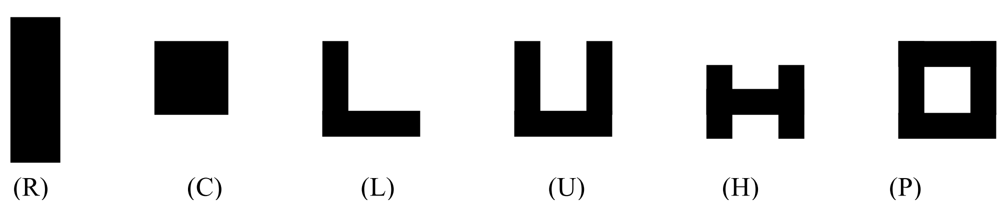

Figure 1: main plan forms of educational buildings

Several structural and functional parameters of the educational building systems have been considered: climate zones, building orientations, volume and compactness features, glazing areas, shading control systems, insulation materials. With the panel data, we have defined a reference educational building (see Table 1).

Table 1: Some features of the reference educational building

Variables	Reference values
Climate	Lyon
Total floor area	10000m²
Number of pupils	750
Heating volume	30000m^3
Multi-story school	3-storied building
Windows and glazing	1/3
External walls	concrete
Roof	flat roof
Indoor temperature	19°C

We have worked with CoDyBa, a software used to determinate the heat flows in a building. It is specially oriented toward optimization of energy performance in buildings (Noel, J. and al. 2001). The heating degrees-hours (HDD) were the quantitative indices to reflect demand for energy to heat buildings. There are derived from daily temperature observations.

The following figures provide results of this study. The figure 2 is showing that the best energy plan form is the square building.

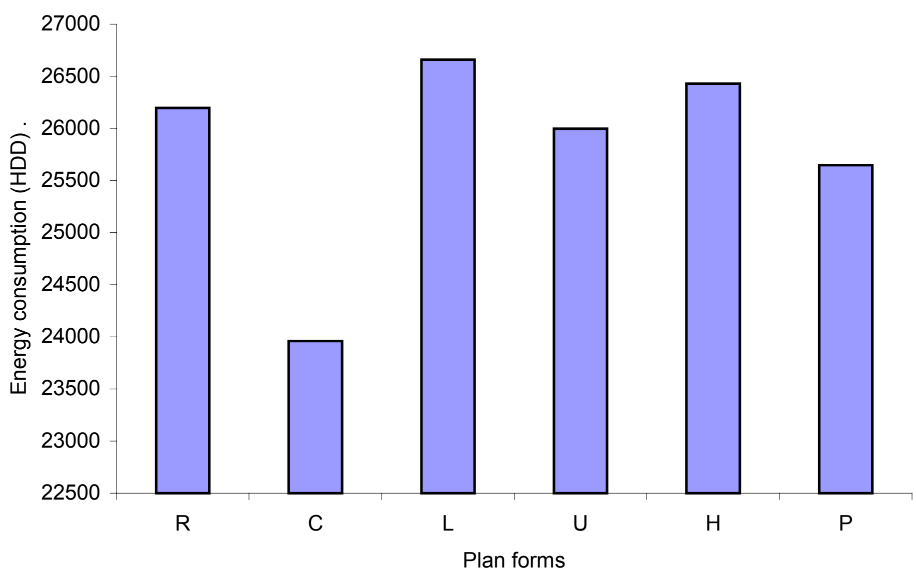

Figure 2: Energy performance of different plan forms

In the figure 3, (o1) means south orientation, and (o2) means 45° in rotation. With a rectangular building, the optimum orientation is with major windows facing south. With a square building, the best orientation also is perpendicularly facing south.

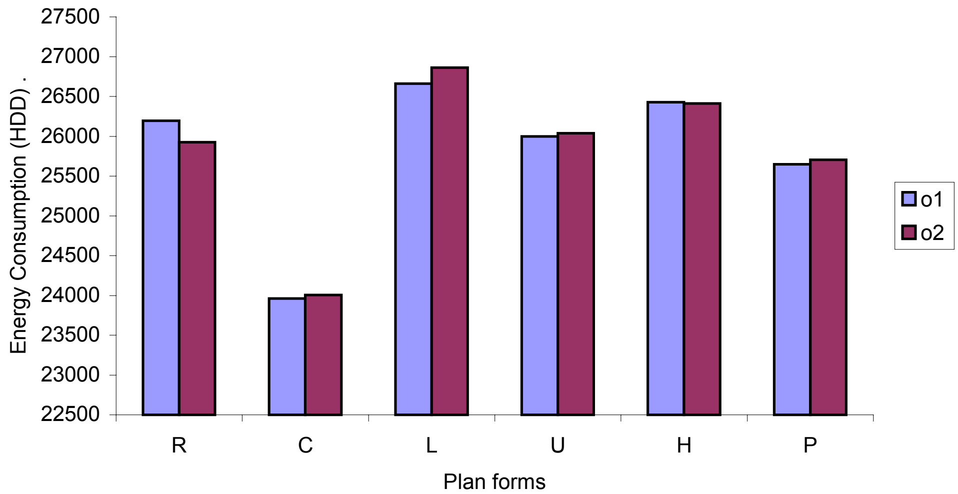

Figure 3: energy consumption with two orientations

In the figure 4, four ceiling heights have been simulated: h1=3metres, h2=3,5m; h3=4m and h4=4,5m.

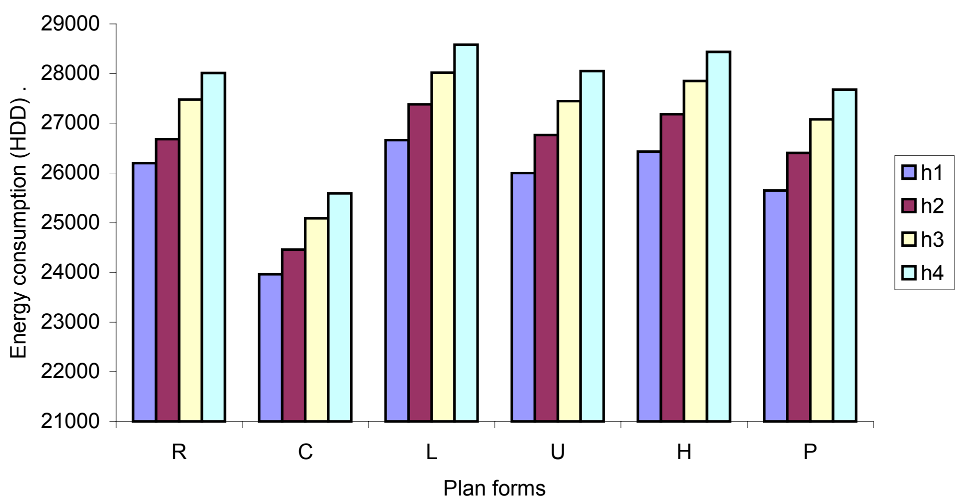

Figure 4: energy consumption with 4 ceiling heights

With this study, we have identify principles of a typological audit for energy retrofitting of educational buildings in Rhône Alpes area:

- the square educational building is the more efficient energy performance plan form.
- the insulation of external walls is one of the most significant retrofitting techniques for reducing the energy consumption.

- the best orientation of a rectangular educational building is with windows facing south.
- the ceiling height of 3 metres is the best way for integrating educational requirements.
- the glazing area of windows have to be limited to 1/2 because of overheating issues in summer.

These results provide heuristic rules for auditors of educational buildings. Moreover, results may be considered in the first steps of the energy audit. With an quantitative identification of energy performance of existing educational buildings, this work improves efficient management for energy retrofitting.

CONCLUSIONS

In the current context, where decision making is becoming extremely complex, this study has shown a new decision way for energy retrofitting of educational buildings.

Taking into account the analytical and systemic approaches of various aspects of the educational buildings, it provides a typological audit method. It allows to reduce the complexity in the first steps of energy analyzing audits. It improves the efficiency of scanning audits. Several heuristic typological features for implementation in the first steps of an energy audit have been quantified: design approach, site and plan form, construction and building fabric, etc.

In order to reduce the energy consumption of existing educational buildings, this typological audit is a new decision support for auditors. It aims to improve knowledge of decision makers regarding the efficiency of potential energy saving measures for retrofitting.

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