Environmental Retrofitting of Educational Buildings - Architectural Aspects of an International Research Project

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ABSTRACT: This paper is based on the comparative analysis of 25 case-studies concerning environmental retrofitting of educational buildings of all levels from 10 different countries in Europe and the U.S. Interdisciplinary teams of researchers participated in an IEA research project (IEA ECBCS Annex 36: Retrofitting of Educational Buildings -REDUCE) aiming at the collection and evaluation of retrofit measures and components used for the environmental rehabilitation of educational buildings in each country. The analysis includes factors of cost, environmental benefits, energy savings, design guidelines, lessons learned and user feedback for each retrofit concept used in the case-studies selected. The data collected is used for the development of an internet-based computer tool for decision makers in the education sector, called the "energy concept adviser", which is the final outcome of the project. The evaluation of the case studies, however, provides useful inspiration and insight on several grounds, as they were carried out in different countries and under different constraints. One of the most important, although not explicitly mentioned aspects of this analysis is pertaining to the architectural dimensions of the retrofitting process and this is the object of this paper. These include both the integrated design concepts for each case study and the evaluation of the architectural quality of the building environment before and after renovation, mostly from the point of view of user comfort and commodity rather than esthetics.

Conference Topic: Recycled architecture.
Keywords: Retrofitting, education, building components

1. INTRODUCTION

Although sustainability issues are mostly approached nowadays as an integral part of the design and construction of new buildings -often involving, depending on their size and complexity, the collaboration of architects, engineers and environmental experts -this is not always easy to achieve in retrofitting.

In fact the decision to refurbish a building is usually the result of many factors pertaining, for instance, to the degradation of its fabric and systems, the obsoleteness of its services or the inadequacy of its spaces for a drastic change in use. The reduction of energy consumption and the resulting environmental impact of a building is rarely one of the prime issues considered for refurbishment. Therefore it is usually not included as one of its goals, and if so only as a secondary one.

Since existing buildings form a large majority of the building stock, it is obvious that the inclusion of sustainability issues in building renovation could have a considerable influence on human eco-systems. This is not easy to implement, however, since building renovation as a process has many limitations, related to small budgets, building and site drawbacks, service and use particularities and, last but not least, lack of energy conservation experience from the part of the decision-makers.

The aim of this research project has been to help remedy this situation in the case of retrofitting of educational buildings.

2. SHORT DESCRIPTION OF THE PROJECT

Educational buildings in Europe and the U.S. have many similarities in architectural design, use patterns, maintenance and energy conservation as well as air quality features. Many of them are in urgent need of renovation showing severe signs of disrepair which might be a source of health hazards to students and teachers, while several exhibit quite high energy consumption patterns, as they have been constructed before the "energy crisis".
3. THE CASE STUDIES: TECHNOLOGIES AND STRATEGIES

3.1 Description of the case studies

A total of twenty five case-studies have been included in this project, of which 5 from Germany and the U.K., 3 from Denmark and the U.S., 2 from Finland, France, Greece and Poland and one from Norway. Most of the schools that have been retrofitted were built in the period 1950-1970 or after 1970, while a few were constructed before 1950 of which one before 1910 [1].

The space distribution of the schools studied has been analyzed and a typology matrix has been formed according to which both School and University case studies have been distributed.

3.2 Retrofitting technologies

Finally the main energy retrofit technologies used are described according to their intended focus in each project, following the same categorization as in the case-study reports: building envelope improvement, heating systems, ventilation systems, solar control and cooling, light and electricity systems and management issues.

As can be seen from the analysis of the case-study reports, the retrofitting technologies used most often in the case-studies are well-established simple conservation measures, such as added insulation to the building shell, window improvement and replacement of heating and lighting with more efficient and better controlled systems. However, more sophisticated but well accepted technologies, such as hybrid or demand-controlled ventilation and daylighting strategies have been applied as well to about 30% of the projects, while advanced or innovative systems such as preheating of ventilation air, innovative insulation schemes, passive solar heating and cooling technologies, atria, active solar or P.V. have been implemented in only a few of the case-studies [2].

As far as energy savings resulting from the implementation of the technologies used is concerned, they range from 55-75% for some projects to 8-10% for others, depending on the retrofitting strategies used in each case.

3.3 Main retrofitting strategies

Three overall strategies can in fact be distinguished [2]:

1. The combination of several technologies in an integrated approach, achieving higher energy savings at longer payback time. This is usually true for demonstration projects, where new and advanced technologies are often implemented and initial cost is not a problem.

2. The emphasis on the implementation of cost-effective technologies only, where smaller overall energy savings are achieved but there are short payback times and an immediate return of the investment.

3. The consideration of the improvement of indoor climate, air quality and lighting comfort as the main retrofitting target, accepting resulting energy savings as additional benefits.

It is useful to compare methodologies and results for projects using each one of these strategies.

4. THE ARCHITECTURAL DIMENSIONS

4.1 The integrated approach

There are two very important aspects of the retrofitting process that are not explicitly mentioned in most case-studies however. The first one has to do with the role of the existing building both as a space system and as a material configuration in the environmental retrofitting of educational buildings, while the second points to the equally important and often neglected role of the user to achieve high standards of air quality and comfort.

In fact architectural design is a very important part of an integrated approach to environmental design and this is also true for retrofitting. In most of our case-studies, however, environmental design strategies were focused on cost-effective technologies, which were mostly considered as an additive feature to the building. Thus the spatial configuration, dimensions and fabric of the retrofitted buildings were often not considered as part of the refurbishment, which was limited to improvement of the building systems only.

Depending on the budget available, the implementation of increased fabric insulation and window improvement was a first step towards the integration of measures related to the building façade, to those pertaining to the heating or lighting systems, thus leading to a more cost and energy-efficient approach, due to synergy effects.
4.2 Retrofitting strategies and architecture

The air-tightness of the façade, however, often demands a new ventilation strategy so that better air quality standards are achieved. At this point the spatial distribution of a building and its dimensions and orientation are crucial for the choice of the natural ventilation strategies to be used. As noted in [3] natural ventilation strategies can be based on morphological characteristics of a building according to its spatial configuration, so that different types of space-related ventilation systems can be distinguished, such as: a) transition spaces, b) stack devices, c) ventilation shafts and d) façade-ventilation, including “double-skin” façade.

Most of these space-related ventilation systems and their combinations are included in the environmental strategies of the case-studies presented, combined with innovative daylighting, cooling and control systems.

The projects discussed below use a holistic approach, resulting in a positive interaction between the architectural features and the environmental retrofitting strategies used, in order to achieve solutions of low environmental impact, well adapted to users’ needs and presenting high levels of air quality and comfort.

4.3 The role of transition spaces

Several examples of the use of atria as the base of a hybrid ventilation concept [4] are included in the case-studies.

- In Bertolt-Brecht School in Germany (D2) two open courtyards were transformed into atria to be used as common rooms and as the heart of the ventilation concept (Fig. 1, 2). In spite of some problems with lighting reduction and winter comfort, mostly related to the change in use, the project achieved user satisfaction and high levels of energy efficiency and comfort as an integrated design.

  In fact, energy consumption for heating was reduced by 75%, while artificial lighting needs dropped up to 77% in several classrooms, according to monitoring results.

- A similar concept was used in the Ioannina School of Philosophy in Greece (G2) where the atrium space [5] was transformed into a winter garden and circulation space with occasional recreation uses (Fig. 3, 4).

  Figure 1: One of the two courtyards of Bertolt Brecht School transformed into an atrium

  Figure 2: Ventilation concept as originally planned in Bertolt Brecht School

  Figure 3: Ioannina School of Philosophy: View of the atrium roof from S.W.

  Figure 4: Ioannina School of Philosophy: View of the atrium space.
Due to the combination of a specially designed solar roof and an array of earth pipes buried under the atrium surface, the atrium space is comfortable all year round and as such it is quite appreciated by the users.

Energy gains are estimated at 31% of annual heating requirements for this part of the building.

4.4 Integration of innovative ventilation systems

Innovative ventilation systems have been used in several case-studies, where natural ventilation strategies have been integrated to the existing building structure, often entailing change in use, dimensions or openings.

- In Egebjerg School in Ballerup, Denmark (DK1) modern heating and ventilation technologies were combined to achieve a healthy indoor climate at a reasonable cost, using ecological materials and natural ventilation of spaces. The integrated design concept developed from a close cooperation between architects, engineers and consultants, and the resulting innovative ventilation system profits from the existing crawl space and double height common assembly room, to achieve pre-heating of ventilation intake and operation of a ventilation chimney for extract air. Another innovative feature is a natural lighting and ventilation collector, integrated to the roof of each classroom (Fig. 5,6).

Figure 5: North view of Egebjerg School

Figure 6: Technical section of the school showing ventilation principle

In this project energy gains were also considerable, since annual energy consumption for heating was reduced from 181kwh/m² to 87kwh/m² while electricity for lighting and ventilation dropped to 22 kwh/m² from 36kwh/m² before retrofitting.

- In another school in Denmark (Enghojskolen School, DK2) the retrofitting concept included a drastic change in the architecture, entailing the creation of a new roof with increased height for classrooms, replacement of all materials by ecological ones and reconstruction of windows in order to achieve a user-operated natural ventilation system (Fig. 7), which not only significantly reduced the building’s environmental impact, but also developed the students’ environmental conscience and ability to actively intervene in order to achieve high environmental standards.

In this project annual energy consumption for heating dropped from 284kwh/m² to 73kwh/m² while electricity consumption was reduced from 72kwh/m² to 39kwh/m² after retrofitting.

Figure 7: Photo showing the interior of a refurbished classroom

- The hybrid ventilation system was also central for a school in Norway (Kampen School, N1) where existing air ducts and ventilation shafts in the building were combined with a new air intake tower and integrated wall system in each classroom to create a non-draft ventilation process (Fig. 8,9).

Figure 8: Kampen School: The new façade
In this case, energy conservation features are integrated to a general retrofitting of the school, including the construction of a new wing joining the two original buildings together and sheltering common spaces, a library, and the new air intake tower.

Besides hybrid ventilation features, a new daylighting system includes window interventions to install light shelves at mid-height and glare control in the classroom as well as demand-controlled lighting, ventilation and heat recovery systems. Low-e and environmentally favorable building materials are employed throughout the renovation process, while L.C.C. analysis is used for the whole system.

As a result of the retrofitting strategy, energy consumption was reduced by 18%, of which electricity consumption dropped by 47% despite higher ventilation rates.

4.5 The holistic approach to retrofitting

A new natural ventilation concept fully integrated to the architecture of the building was also central to the energy retrofitting strategy of Grove House at Thames Valley University, UK (UK3). Renovation of the building included a change in use, from offices to classrooms and computer laboratories, while both the external appearance of the refurbishment and its energy retrofitting strategy were vital for project implementation: the first because the building lies in a conservation area, the second to help the University maintain its Energy Efficiency Accreditation (Fig. 10).

The building acted as a pilot for its integrated environmental retrofitting system. It includes a passive stack and façade-ventilation system, as well as night cooling, vacuum tube solar thermal panels, more efficient heating and lighting systems with BMS controls and waterless urinals.

The mixed-mode ventilation is well integrated to this heavy-mass building with no problems to its façade: windows have been replaced to include air inlet grilles and the suspended ceiling in each laboratory is altered so that an air plenum is formed between it and the existing building concrete slab, from where fresh air is supplied to the building. The air is then drawn across the rooms into the corridors through acoustically treated vents and finally to the stairwells used as passive stacks to draw stale air out via roof mounted terminals (Fig. 11).

Night cooling works in the reverse way to lower the temperature of the large ceiling concrete mass, while wall transfer grilles are placed throughout the building to allow the flow of air. The system is very successful both from the point of view of environmental impact and water conservation and has low maintenance and running costs, while it required no structural alterations to this very sensitive building. Due to this combination of heavy mass building and cross and stack ventilation there is improved air quality, internal temperatures are substantially reduced in the summer, while large ventilation openings create no drafts in cooler periods.

Besides the benefits mentioned above, electricity costs for hot water were reduced from £12,500 p.a. to £700 p.a., while gas consumption was reduced by 8-10% despite longer operating hours for the building, according to monitoring results.

Finally in the Chemical Engineering Building in Greece (GR1) the retrofitting concept included an integrated design combining standard as well as innovative energy conservation measures. They include a double skin hybrid ventilation system using a combination of passive and PV technology (Fig. 12), the conversion of existing light shafts into light and ventilation ducts for the laboratories (Fig. 13), the combination of natural and artificial lighting, including the creation of light shelves and new shading to increase visual comfort in offices, the design of a new covered atrium to create an...
additional meeting space and the use of **attached sunspaces** for some laboratories in order to integrate existing catwalks [6].

**Figure 12:** View of the Chemical Engineering building after retrofit

The energy retrofitting strategy was well integrated to this **heavy mass building**, where **ample transition spaces** occupied the majority of covered spaces presenting particular problems of comfort due to their lack of heating and natural lighting.

**Figure 13:** Operational section of retrofitting systems, a. Ventilation ducts, b. Light shelves

Operation of the system was based on the idea of dividing the building into three thermally independent parts, in order to best proceed with control and monitoring of the entire complex [5].

As calculated using TRNSYS’s software, energy consumption for heating is reduced by 34.5% and this for cooling by 68.6% using a combination of simple energy conservation measures [7].

### 5. CONCLUSIONS

As a result of the above analysis and the comparison of the resulting energy conservation and user evaluation features of the case-studies presented, it follows that the inclusion of architectural characteristics of the building to be refurbished, both as a space system and as a material configuration is essential to the successful integration of environmental retrofitting strategies in educational buildings [8]. Besides high energy savings, lower environmental impact and improvement of indoor climate, integrated projects include better use and appreciation of improved or extended spaces in the building or around it and increased involvement of students and teachers in the operation of the system, so that high environmental standards are achieved.

### 6. REFERENCES