Integrated design optimization of school pavilions – a case study in Milan

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ABSTRACT

The case study in question is that of the refurbishment of a building constituted by four school pavilions built in the post-war period of the 20th Century with very lightweight reinforced concrete arches and vaults. Different retrofit hypotheses have been evaluated by the means of the ESP-r software tool, taking into account heating energy consumption, summer free-floating temperatures, daylighting and space use. Three design solutions have been compared, leading to the suggestion to reject the most radical design hypothesis and improve the original configuration by the means of an adjoining sunspace.

1. INTRODUCTION

The study here presented is aimed at the retrofit of a building composed by some pavilions at the Technical Industrial Institute “Giangiacomo Feltrinelli” in Milan, and is part of a larger consultancy work.

The pavilions were originally built with constructive and spatial criteria typical of the industrial aisles in the post-war period of the last century. They are vaulted with very slender, prefabricated, reinforced concrete arches, lightened by transversal holes. Each arch is connected at its base to two continuous reinforced concrete beams at eaves height and by a slender reinforced concrete beam at the top of them, and has to be constrained by a steel tie at its base level. The span between arches was closed by hollow clay slabs completed by a non-reinforced concrete screed.

The clerestories at the top of each pavilion’s roof are constituted by a continuous horizontal strip of windows facing west.

The urgency for the building refurbishment/retrofit/upgrade was primarily caused by the fact that the building was considered no more structurally safe in some zones. And both the users and the designers suggested that the refurbishment of the building could be brought on not only by reinforcing or supporting its structures, but also by improving in the process its spatial and functional features. The results were that the public administration of the Province of Milan, which manages and now owns the complex, in 2005 took the decision to radically modify the pavilions, in order to couple the needed structural improvements with spatial modifications suitable to increase the built volume and widen the range of functions that can be hosted in it, for instance “opening” some parts of it to the population of the district.

The study here presented was a part of the activities undertaken to support the decision process. With this aim, a selected range of design hypotheses has been evaluated, taking into account heating energy consumption, summer temperatures attainable through sun shading and natural ventilation, daylighting, and space use.
2. THE COMPETING DESIGN HYPOTHESES

The main design hypotheses were taken into account. A first architectural intervention proposal – base case (a) – is aimed at the conservation of the pavilions as they are, which may be done by coupling the reinforced concrete arches with steel arches bracings, or by supporting them with a load-bearing, shell-like concrete vault on top of them. The conservation of the original morphology could also be attained by substituting the original vaulted roof with a new one assembled with modern lightweight components. In this case, a modification of the clerestory’s height can be taken into account, to improve daylighting. A second design hypothesis - case (b) - implies the substitution of the existing vaults with new ones, running in a direction orthogonal to the original ones, and accompanied by an increase of 1.15 m of the height at the eaves and by the division of some parts of the full-height internal space of the pavilions in two storeys.¹

A third design proposal (c) was characterized by the construction of a wood-framed sunspace on the south wall facade of the pavilions, used as solar collector and as a corridor at the second floor level.

3. PERFORMANCES OF THE CONSIDERED DESIGN SOLUTIONS

3.1 Thermal performance

The second pavilion from west has been modelled with regard to each of the considered design hypotheses using the ESP-r software tool. Due to the destination of the pavilions (industrial laboratories not used during evenings and nights), their envelope has been just lightly insulated (with 4 cm wood fiberboard at the inside face of the walls and 8 cm glasswool near the outside face of the roof). The sunspace for case (c) was double-glazed. A mass flow network has been created in the considered thermal zones, taking into account the windows and clerestories. The operativity of the windows has been modelled imposing them to open from 8 a.m. to 17 p.m. above 24 °C (db). An ideal control has been imposed to the zone for winter heating (20 Kw), active from 5 a.m. to 16 p.m., trig-

¹The roof structure in this case is really no more a vaulted structure, but a simpler planar structure connected to columns of varying heights.
ileged to keep the zone db temperature above 16 °C. Casual gains have been scheduled taking into account space usage, lighting and machineries.

With regard to space heating requirements, a considerable degree of advantage has been found in case (a) over case (b), mainly due to the volume increase of the second solution; and a certain degree of advantage in case (c) over case (a), mainly due to the solar gains of the sunspace. In case (c), the wall and floor of the sunspace were tested both as not thermally insulated – case (c1) - and as thermally insulated (c2). In the latter case, the sunspace works as an air-heater. Anyway, the improvements produced by the sunspace are rather small, mostly due to its small volume compared to the pavilions'.

As expected, the temperature differences between cases are much higher for the sunspace, and are already a problem during Spring. In case (c2) both dbts and mrts are unacceptably high. In case (c1) dbts are much lower, but mrts are still too high. But with a horizontal shading device on the sunspace facade and a tightly-spaced lamella shading device on the sunspace roof – design case (c3) – both the dbts and the mrts ranges are found to be acceptable. This suggest that the sunspace should be mandatorily coupled to shading devices during Spring. The hypothesis here is that the horizontal overhang serving the sunspace façade does not need to be movable, while the one serving the sunspace roof should be movable, not the compromise winter solar gains. A textile device not adherent to the roof (to allow for ventilation from the upper roof vents) and seasonally removable may here be advisable. In this hypothesis, ventilation is made possible by windows on the sunspaces façade and roof for about 30% of the transparent surface.
Figure 12: Air db temperatures and mean radiant temperatures in the sunspace for case (c1) – base – (c2) – as an air-heater – and (c3) – base, sunshaded. April 15-25th.

Solution (a) produces lower temperatures than solution (b) in the pavilions also in summer.

And also in summer air d.b. temperatures show an increase in the pavilions from case (a) to (c1) to (b) to (c2). This suggests the need to enlarge the size of the operable windows. The hypothesis adopted here was bringing them to about 50% of the transparent surface - solution (c4). This solution in June lowers the pavilions resultant temperatures of more than 1 °C.

Figure 13: Free floating resultant temperatures in the pavilions for cases (a) and (b) – June 1-10th.

In summer the sunspace overheating seems to be severe especially for the case of the sunspace used in winter as an air-heater.

Figure 14: Free floating resultant temperatures in the pavilions for cases (a), (c1) - with sunspace - and (c4) - with sunspace and enhanced ventilation. June 1-10th. (Ambient db temperatures not shown here for clarity.)

This, coupled with the fact that the solution does not produce great advantages in winter, suggests the opportunity to opt for the configuration of the sunspace not isolated from the adjoining pavilion.

Considering the described thermal results, the configuration (c1) – sunspace –, seasonally operable, to be transformed from Spring to Fall in the configurations (c3) or (c4), sunshaded, seems on the whole the most suitable design solution among the analysed ones.

3.2 Daylighting

The daylighting performance of the design hypotheses have been tested through the use of Radiance softwa-
re tool coupled with ESP-r, in order to evaluate the diurnal daylight factors at the height of 90 cm from the floor surface of the pavilion. With this aim, the base case has been evaluated with respect to three clerestory heights (and, therefore, areas): as-is (a1); doubled (a2); tripled (a3). As expected, the results have shown a significant mean increase of the daylight factors from case (a1) to (a3). But not less important, cases (a1), (a2), (a3) have shown a greater homogeneity in the daylight factors distribution compared to case (b). The importance of the homogeneity of illumination distribution levels is here high, because it allows for non-situated work; and in an industrial laboratory, flexibility of space usage is a major requirement, due to the fact that often spatially distributed work may take place there.

The base case (a1), produces a distribution of daylight factors that is rather homogeneous with respect to the length of the room - indeed, it is an architectural solution which has been consolidated by time and use -, but it does not produce high daylight factors (Fig. 15). This is due to the fact that the height of its clerestory windows is rather small. That architectural solution derives indeed from a typological conception aimed to produce homogeneous illuminance levels without a significant increase of heating energy consumption in winter. But the new, future possible usages of the building may require higher illuminance levels. Moreover, the daylight factors in question are not evenly distributed with respect to the room width.

Case (a2) produces a mean increase of the daylight factors compared to case (a1), making them suitable for a wider range of activities, maintaining their homogeneous distribution in the room length and increasing it in the room width. Both facts are very positive, allowing for a wider range of usage types. Moreover, this can be obtained at just a little expense of energy-efficiency, provided that energy-conserving building envelope components are adopted for the glazing systems.

Understandably, case (a3) shows a further mean increase of the daylight factors compared to case (a2), maintaining their even distribution.

Case (b) shows instead a decrease of the daylighting performance of the pavilions, caused to the non-homogeneous distribution of the daylight factors. This is presumably due to the reasons that: 1) the height of the clerestory windows is not constant, being greater at the centre of the room and smaller at the ends; 2) the clerestory windows do not extend to the extremities of the building. The homogeneity of the daylight factors distribution is here increased by four pseudo-horizontal skylights (accounted for in the simulations, but closed in separated rooms in the original design hypothesis).

4. CONCLUSIONS

The analyses have suggested that the most advantageous solutions for the environmentally-conscious refurbishment of the school building in question is attainable with an approach suitable to produce innovation on top of a design soundness typical of the past industrial age. More precisely, they suggest the opportunity to add a seasonally operable sunspace to the south facade of the pavilions and to enlarge their clerestory windows. The latter operation may be viable in the case that a radical rebuilt of the roof ends up to be advisable at construction level.

REFERENCES