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Energy Efficiency and Architectural Heritage: The Reconstruction of the French Pavilion in Zagreb

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Abstract

The exhibition pavilion of the Republic of France was built for the Zagreb Fair during the years 1936 and 1937 at 25 Savska Street 25 in Zagreb according to the design of the French architect Robert Camelot and the civil engineer Bernard Lafaille. The French Pavilion represents a unique engineering innovation, since a thin steel shell was applied for the first time as a load-bearing structure in high-rise building. Therefore, it is a building of exceptional cultural and historical, as well as technical and technological value. The reconstruction design envisaged that the Pavilion would keep its original use as an exhibition space with the possibility of holding some other public events such as lectures, promotions, round-table discussions and smaller performances. In order to enable the use of the Pavilion all year round, it was necessary to adapt the Pavilion appropriately to contemporary standards. In this process, special attention was given to energy efficiency with a contemporary treatment of the perimeter elements of the Pavilion structural system (non- and load bearing structures), which did not damage the authenticity of its idea and design in any segment.

Keywords*: energy efficiency, reconstruction, cultural heritage, the French pavilion, Bernard Lafaille.*

1. Introduction

The relocation of the *Zagreb Fair* to the grounds of the furniture factory "Bothe & Ehrmann" in Savska Street in 1934, enabled its spatial development on approximately 30,000 m^2 of a mostly vacant lot. This in turn provided an opportunity for the international activities of the *Zagreb Fair* once the national pavilions, financed by parent countries, were built. At the end of 1935, an architectural competition for the *Zagreb Fair* was launched. The first prize was won by the architects Hinko Bauer and Marijan Haberle, who were also entrusted with the realisation of the project. Until October 1936, when the first exhibition on the new location was held, according to the competition design only the first phase of the building of the Zagreb Fair complex had been finished. The national exhibition pavilions of France, Italy, Germany and Czechoslovakia were designed by foreign architects and they were built in the period between 1936 and 1938. The exhibition pavilion of the Republic of France was built in 1936 and 1937 according to the design of the French architect Robert Camelot (Reims, 1903 – Pariz, 1992), who worked for the Jacques and Paul Herbé architectural bureau, and the civil engineer Bernard Lafaille (Reims, 1900 – Pariz, 1955). The construction was completed by Zagreb craftsmen.

The French Pavilion represents a unique engineering innovation, since a thin steel shell was applied for the first time as a load-bearing structure in high-rise building. Therefore, it is a building of such exceptional cultural and historical, as well as of technical and technological value, that it transcends the boundaries of local significance. This statement was supported by the work of Bernard Lafaille and Robert Camelot in the period after the Second World War, when they frequently applied technical and technological achievements of their developmental phase of which the French Pavilion in Zagreb was an initial part. While Lafaille was dedicated to industrial architecture (hangars, silos, bridges and dams), as well as to the cooperation with the leading architects of the post-war period, for example with Le Corbusier, on the projects of Unité d'Habitation, Camelot has been remembered as one of the designers of the Paris Centre for New Industries and Technologies (CNIT, 1950), the nucleus of today's business centre of Paris – La Défense. Apart from the French Pavilion in Zagreb, he also designed a pavilion for the world exhibition in New York (1939) with the Herbé brothers.

Under the directive of the Regional Institute for the Protection of Cultural Monuments in Zagreb, the French Pavilion was preventively protected in 1987, while under the directive of the Administration for the Protection of Cultural Heritage of the Ministry of Culture of the Republic of Croatia in 2003 it was listed in the Register of Cultural Assets of the Republic of Croatia.

2. The original design and construction of the French Pavilion 1936-1937

The national exhibition pavilion of the Republic of France was erected in the centre of the *Zagreb Fair* complex. Its position and shape were already defined in the first-prize winning architectural competition design of the tandem Bauer – Haberle.

In the period between August and December 1936 all design documentation was created, while the obtaining of necessary building permits for the construction of the Pavilion was prolonged as long as to the spring of 1937. The preliminary design was signed by the architects Robert Camelot together with Jacques and Paul Herbé, while the structural designer was the civil engineer Bernard Lafaille. The development of the detailed design was entrusted to Vjekoslav Faltus, architect from Zagreb. The contractors were Zagreb craftsmen who also carried out the contract designs. These were the Construction Company *Braća ing. Faltus* (concrete details), the Carpentry Šoch & Sakra (the details of the wooden structure and façade), and the Engineering Workshop and Foundry *Braća Ševčik* (details of the steel structure). Under deadline pressure the Pavilion was built during the six winter months. The opening ceremony took place on 17 April 1937 at the beginning of the "XXVII. International Specialized Sample Fair". The opening of the Pavilion and the spring fair were followed by two years of additional work and repairs caused by the untimely opening of the Pavilion as well as by design and construction flaws. Most problems were caused by moistening and water dripping into the interior of the Pavilion, because of the condensation on the soffit of the steel tin roof. The analysis of the designing and construction of the Pavilion, including the choice of the contractors and building methods, informs us about a tight deadline in which the project was conceived and realized, the kind of deadline which is certainly a common characteristic of the organisation of large fairs.

The Pavilion is conceived as a cylindrical single-space structure of an irregular curved surface, covered with a suspended roof (*la voile mince*) in the shape of a reversed shallow cone 32.30 m in diameter made of trapezium steel tin panels 2 – 3 mm thick.

The roof rests at a height of 13.50 m above the ground on a ring-like series of 12 steel tubular columns 80 cm in diameter and 3 mm thick, fixed on short reinforced-concrete bars that stick out from the concrete base. The roof structure is stretched under the weight of the central circular skylight which also functions as a precipitation collector, while the whole structure system is stabilized with a concrete ring beam in a steel tin box, laid directly on the columns. This construction represents the first tensile stress roof structure of a modern conception in the history of Croatian architecture, and in the area of weight (18 kg/m^2 of a roof over area) it is a kind of record. The cylindrical walls are made of concrete to the height of 4.9 m, while the upper zone is made of wooden frames with outer and inner panelling divided by ventilated cavity. Within the wooden structure, narrow vertical window openings are alternatively interpolated, while additional natural light is provided by a circular skylight in the middle of the roof structure. The Pavilion has three equally important entrances emphasized by glazed, wooden railing of almost the full height of the Pavilion. The mentioned window and door openings were glazed originally with single-layered glass, while the roof skylight was composed of two glass membranes in separate steel frames. The floor surface of the Pavilion is raised above the ground with 8 steps and it was made of concrete with shallow, geometric graphics. In the basement area, there are three separate spaces and only one is connected directly with the Pavilion interior. The volumes of the basement spaces can be observed on the cylindrical perimeter wall of the Pavilion.

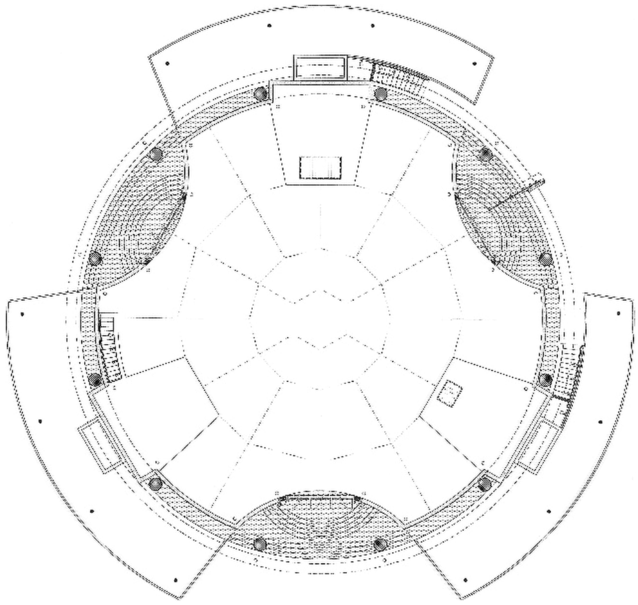


Fig. 1. The French Pavilion, ground-floor plan (contract design, 2010.)

The building is characterised by the combination of the architectural idea about a representative central space, enabled by an innovative construction solution, with the application of building industry materials that normally characterize a building of limited duration.

3. The history of use and former renovation and adaptation designs of the French Pavilion

This masterpiece of modern architecture kept its original use as an exhibition space for the latest technical achievements for a very short time. Ever since the *Zagreb Fair* was moved to its present location in New Zagreb in 1956, the French Pavilion has not been given more appropriate use within the Student Centre but the one of the storage of the nearby Theatre &TD. Inappropriate use of the attractive space of the Pavilion in the second part of the 20th century was occasionally accompanied by the initiatives for its renovation. As a matter of fact, three designs for its renovation and adaptation were made, there were several studies of the whole complex including the Pavilion, as well as numerous exhibitions about the creation, history, possible use, and renovation of the Pavilion. In the early 1990s, the Pavilion entered the period of relatively intensive new use as a theatrical stage. Recognized as an exceptionally valuable theatrical space, owing to the geometry of its interior, the Pavilion aroused great interest of cultural workers. However, the poor condition of the Pavilion questioned any further use for public performances without previous renovation. Since the renewal did not take place, at the end of the 1990s the French Pavilion was definitely closed for any kind of public use due to safety reasons and until 2009 it was used as storage.

4. The design of renovation and reconstruction of the French Pavilion between 2007 and 2011

The latest initiative for the renovation of the French Pavilion was a part of "The Strategy Proposal of the Renovation and Revitalization of the Student Centre of the University of Zagreb". The group of experts concluded that the French Pavilion as a unique building had to be reconstructed to its initial state with some necessary technical alterations which would enable the implementation of contemporary standards.

Within the task that was defined by the mentioned Strategy Proposal, the Institute for Built Heritage of the Faculty of Architecture of the University of Zagreb made a detailed architectural survey of the French Pavilion current state in the spring 2007 with all the damages delineated in it, including the evidence of corrosion damages on the load-bearing steel structure. Six columns reachable from the scaffolding were probed and the damages of the steel tin roof were evidenced on the basis of visual examination. The results of this preliminary research showed that the entire surface of the columns and more than one quarter of the surface of the roof were suffering from corrosion. At the meeting of the project coordination in July 2007 with the participation of the French conservator Pierre-Antoine Gatier, it was concluded that a segment of 1/12 of the Pavilion had to be examined in its entirety, both the part of the load-bearing steel structure and the part of the concrete base and wooden panelling.

The research was carried out by the Croatian Conservation Institute and the Croatian Society for Materials and Tribology in March and April 2008. Researches of the Croatian Conservation Institute included the analysis of the composition of the steel and the welds on the columns, the research of the plaster layers and the kinds of binders on the concrete base, as well as the research of the painted layers and the kinds of wood on the surface, so that the same kinds of materials, paint coats, paints, binders and alloys would be used during the reconstruction.

Fig. 2. The French Pavilion after completion in 1938 (top), the state in 2007 (middle) and after reconstruction in 2014

The examination of the Croatian Society for Materials and Tribology on a segment of the load-bearing steel structure indicated a damaging influence of corrosion in the form of holes in steel tin and the thickness reduction of the column walls up to 40% in comparison with the originally designed thickness. Similar results were obtained by the measuring of the thickness of the roof steel tin plates. In comparison with the originally designed thickness, the reduction of the section amounted to 30%. The latter researches enabled the making of calculation models for the load-bearing structure which indicated an increased main strain due to advanced corrosion of the load-bearing structure which exceeded permitted limits.

All the mentioned researches as well as the calculation model of the present condition of the load-bearing structure suggested the need of a complete reconstruction of the steel load-bearing structure and the wooden surfaces, except for the concrete base of the Pavilion that was scheduled for repair work.

The preliminary design of the renovation and reconstruction of the French Pavilion (The Institute for Built Heritage, July 2008) defined the use of the Pavilion as an exhibition space with partially polyvalent character which created possibility of holding lectures, presentations, university graduation ceremonies, and potentially performances in accordance with unpretentious technical capabilities of the Pavilion, determined by the need for the preservation of the original spatial qualities of the interior. The spatial and functional disposition of the utility rooms, in fact of the three basement volumes, was also defined. The design envisaged modern toilets replacing the original ones, a heating substation and a technical equipment and furniture storage.

The aspect of saving thermal energy and thermal protection was also included in the preliminary design. The calculations of the heat transfer coefficient and the steam diffusion in terms of saving thermal energy were made. All existing perimeter structures showed dissatisfying values of thermal protection and energy saving according to contemporary standards. The occurrence of condensation on the inner surface of the roof structure and windows was proven. Therefore modified sections with additional layers for the purpose of fulfilling the basic requirements of thermal protection and saving the energy of the building were proposed.

The detailed design of the renovation and reconstruction from April 2009 included the design of an overall thermal protection and energy efficiency system. According to the requirements of the Institute for the Protection of Cultural Monuments and Nature of the City of Zagreb, it was decided that because of the preservation of the authenticity of the Pavilion additional layers of thermal insulation on its reinforced-concrete base would not be applied. The base of the building should be preserved in its original thickness, after a possible repair with a thin plaster in order to protect the structure. According to the *Construction Act*, after obtaining a written consent of the Ministry of Culture, it is allowed to depart from the basic requirements for a building (in this case from thermal protection and saving energy), if they would disturb the important features of the monument. The design envisaged the heating of the whole space of the Pavilion including the basement area. The room temperature planned in the design for the heated part of the building was estimated at an average between +18 and 20°C. Thermal energy for heating is provided by hydronic radiant floor heating.

Anticipated changes in the way the building will be used and the resulting microclimate changes are not expected to lead to building damage (the degradation of the structure and section layers).

The design of the Pavilion from the aspect of saving thermal energy and thermal protection was made according to the *Technical Regulations about Thermal Energy Savings and Thermal Protection in Buildings* that were valid at the time as well as on the standards to which these regulations referred.

The design envisaged that the light, wooden panels had to be thermally insulated in the section with a layer of rock wool lined with glass fleece on the ventilated cavity. On the warmer side of the thermal insulation it was necessary to build a vapour barrier.

The walls below the ground in the basement area remained in the previous condition and on the accessible parts waterproofing protection and thermal insulation with extruded polystyrene XPS panels impregnated on the outer side with an HDPE membrane (for protection) were applied. Drainage was laid around the building. The parts of the basement walls inaccessible from the outside were thermally insulated on the inner side with extruded polystyrene XPS panels with the obligatory application of a vapour barrier.

The new floor on the ground of the Pavilion, below which floor heating was installed, includes thermal insulation on a new waterproof layer laid on the existing levelled off concrete base and in the same way the floors on the ground of the basement area of the Pavilion were made. Thermal insulation with extruded polystyrene XPS panels was applied. The ceiling over the basement area (inter-storey construction) remained in its previous state. The roof of the building made of steel tin was thermally insulated with a layer of sprayed up urethane expanding foam with the final layer of sprayed up waterproofing material. The thermal insulation is self-adhesive and sticks to the surface. The layers and the insulation of the roof were applied in accordance with the detailed instructions and descriptions of the producers. The three cross gutters draining under the roof were covered with a layer of rock wool covered with aluminium foil to prevent condensation on the superficial area of the pipe. The flat roof over the basement area was thermally insulated with extruded

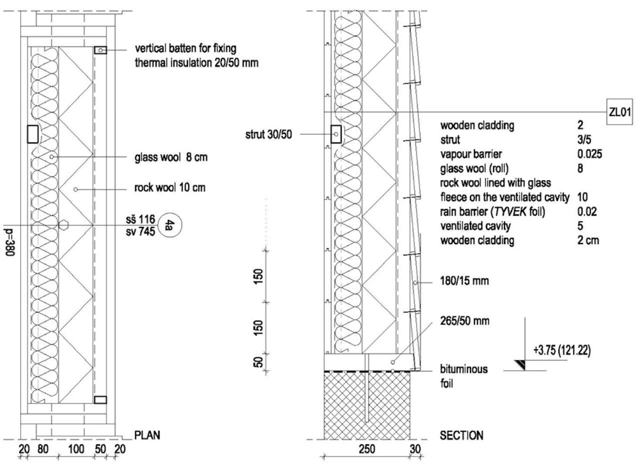


Fig. 3. Section of the perimeter wooden walls showing the application of thermal insulation and supporting layers within the originally hollow cavity of wooden panels.

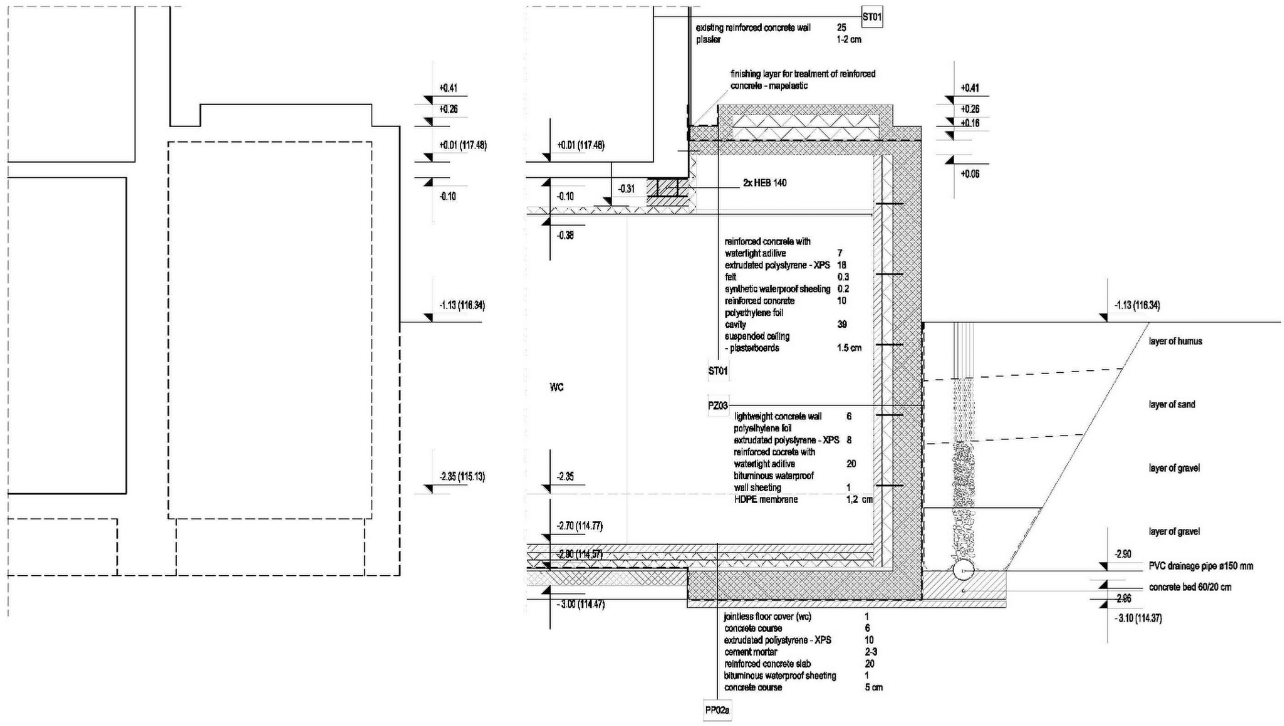


Fig. 4. Longitudinal section through one of the reconstructed basement segments showing the outer walls insulated on the inner side, partially insulated roof slab and new drainage layers.

polystyrene XPS panels and protected with synthetic waterproof insulation.

The wooden frames of fixed windows are glazed with insulating glass LOW-E 4+9+4 mm. The wooden entrance door has a thermally insulated wing and is glazed with insulating glass LOW-E. The roof skylight is made of a double metal frame. The upper frame is glazed with double laminated safety insulating glass LOW-E 4+12+4+4 and the lower one with single glazed laminated safety glass.

Due to the planned improvement of the thermal insulation values the heat transfer coefficients (U-values) are lower than values required by the Technical Regulations, except for the reinforced-concrete outer wall to which it was not allowed to apply any layers for the purpose of thermal protection and energy saving. This departure from U-values does not cause building damage (condensation).

All perimeter structures were designed in such a way that they reach satisfying values of thermal protection (except for the reinforced-concrete wall), that the ones exposed to great temperature changes are stable and that within their composition and on their surface there are no occurrences of unwanted condensation of steam.

Due to the impossibility of complete thermal insulation repairs of the building the transmission heat loss coefficient per surface area unit of the building heated part H_T’ [$W/(m^2{\cdot}K)$] is higher for app. 30% than the permitted values as well as the annual thermal heat demand per volume of the building heated part unit Qh’ ($kWh/m^3{\cdot}a$) which is higher for app. 21% than the permitted values.

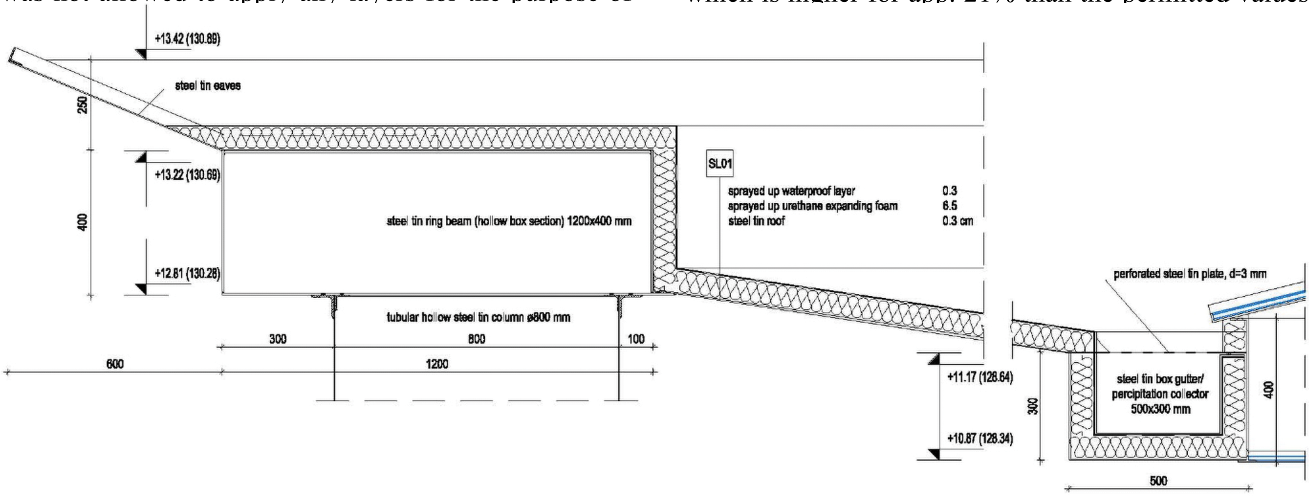


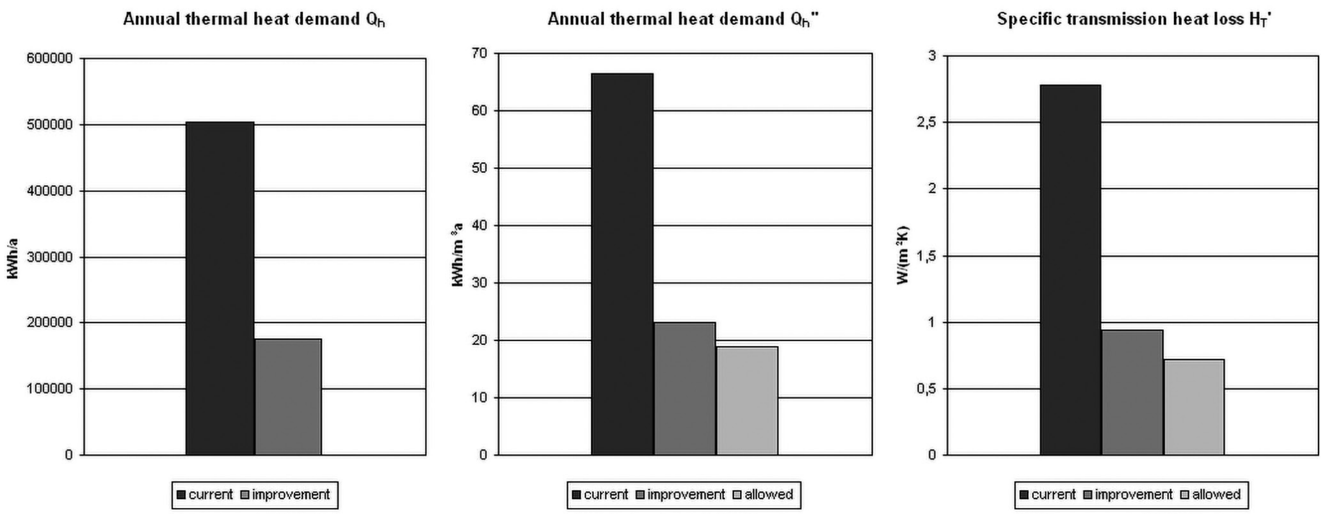
Fig. 5. Section through a segment of steel tin roof showing the application of sprayed up thermal and waterproof insulation; perimeter steel tin ring beam is shown to the left and the box gutter, adjacent to the roof skylight, to the right.

Table 1. Comparison between current and improved U-value.

Type of building structure	U-value current (W/m²K)	U-value impro-vement (W/m²K)
ZM01-wall structure-reinforced concrete	3.76	3.42
ZL01-wall structure-wooden	1.25	0.18
PZ01-basement wall-reinforced concrete	3.75	0.50 – 0.58
PP01-floor structure-the pavilion	3.55	0.32
PP02-floor structure-basement	4.33	0.32
ST01-flat roof-reinforced concrete	4.90	0.39
SL01-steel tin roof	5.46	0.29
roof skylight	3.50	1.80
window	5.10	1.80
door	2.90	2.00

Table 2. The review of the Pavilion energy consumption

Characteristic			
superficial area-building heated part A (m²)	2,664.09		
volume-building heated part V (m³)	7,501.58		
shape factor f_o (m^{-1})	0.36		
usable building area A_K (m²)	674.00		
	current	*impro-vement*	*allowed*
annual thermal heat demand Q_h (kWh/a)	503,230	176,133	–
annual thermal heat demand Q_h'' (kWh/m³a)	66.47	23.02	18.97
specific transmission heat loss H_T' [W/(m²K)]	2.78	0.94	0.72
coefficient transmission heat loss H_T (W/K)	7,416.17	2,495.16	–



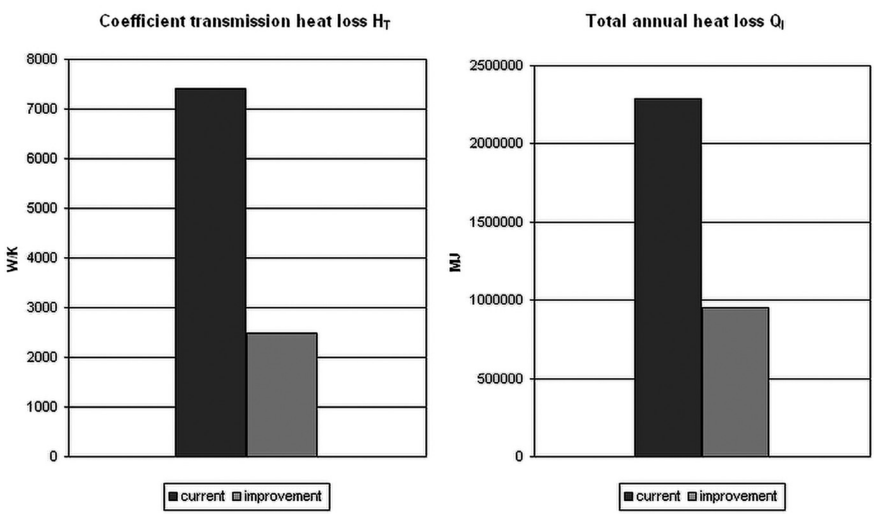


Fig. 6. Graphs showing improvements regarding heat demand and loss.

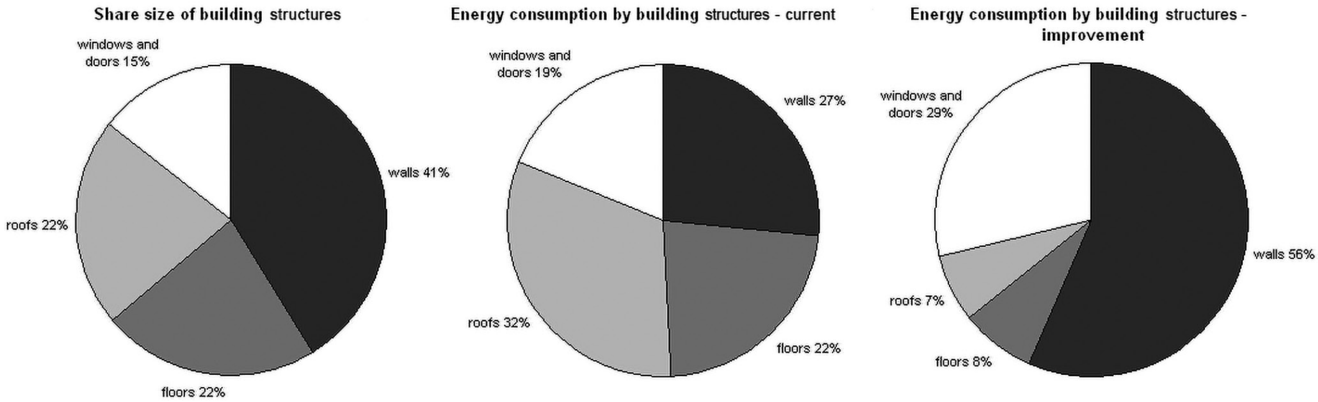


Fig. 7. Graphs showing percentage of building structures and their previous and improved energy consumption.

Conclusion

Exceptionally proportional, particularly impressive in its interior the French Pavilion entered the history of building because of its specific load-bearing metal structure, the author of which was Bernard Lafaille: 12 hollow tubular columns 80 cm in diameter and made of only 3 mm thick steel support at a height of 13.50 metres a ring beam on which a membrane in the shape of a reversed truncated cone 32.30 m in diameter is suspended. A membrane of 820 m^2 in area and 2 mm thick is made of trapezium steel tin panels that were prepared in advance in a workshop and then welded on the spot. As far as the weight is concerned this construction represents a kind of record – 18 kg/m^2 of a roof overall area. Designed in such a way as to bear only tensile stress, the roof structure is suspended under the weight of the central circular skylight and it therefore represents the first tensile strain roof structure of a modern conception. The building is characterized by the combination of the architectural vision of a monumental central space, enabled by an innovative constructional solution, with the construction work of the Pavilion done by the application of some common materials of the building industry that normally characterize a building of limited duration.

The design of the renovation and reconstruction of the French Pavilion at the Student Centre Zagreb envisaged restoring the original use of the building, the one of an exhibition space, with the possibility of occasional organisation of some other public events within the framework of university activities. In order to enable the use of the Pavilion all year round, ultimate technical solutions were found in the treatment of perimeter structures with special emphasis on energy efficiency. Since the French Pavilion is a protected cultural asset, it was impossible to intervene by adding the layers of thermal insulation in order to satisfy the prescribed thermal insulation features on all perimeter structures without threatening its authenticity. The outer reinforced-concrete walls had to be preserved in its original thickness and under the existing conditions without the possibility of adding thermal insulation layers at the request of the Institution for the Protection of Cultural Monuments. For this reason, the heat transfer coefficient U of some walls does not satisfy the prescribed values. By calculation of the condensation it was proved that on and in the reinforced concrete walls the occurrence of unwanted amounts of condensation will not happen.

According to the *Design of the building in regard to saving thermal energy and thermal protection*, all other building elements and building structures under the planned exploitation conditions satisfy the demanded requirements.

Because of the inability to secure complete thermal insulation repairs of the building, the transmission heat loss coefficient per surface area unit of the building heated part H_T’ [$W/(m^2 \cdot K)$] and required annual thermal heat demand per unit of the volume of the building heated part Q_h’ ($kWh/m^3 \cdot a$) are higher than the permitted values. However, since it is a case of a protected cultural asset according to the *Construction Act*, after obtaining a written consent of the Ministry of Culture, it was allowed to depart from the basic requirements for a building, in this case from thermal protection and saving energy.

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