Environmental Design for Petrobras: A Step Forward in Brazilian Architecture

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ABSTRACT: In 2004 the Brazilian Petroleum Company, Petrobras, organised a national design competition for its new research centre, CENPES II. The architectural complex of over 100,000m² is planned to be built in 2006/07, by the Guanabara Bay in Rio de Janeiro, Brazil. The competition brief asked for an “environmentally friendly” solution, where issues of daylight, natural ventilation and energy generation were mandatory. The winning scheme was inspired by the integration between the “carioca” architecture (local from Rio) and the advents of contemporary technology. Following principles of environmental design, the local hot-humid climate had major influence in the architectural proposal. Since the conceptual stage, the design process was informed by intermediate environmental assessments, which were developed through a series of analytical studies using a group of advanced simulation tools. With special regards to the thermal and energy performance, the assessment came across the mixed-mode strategy, showing the potential of up to 30% of natural ventilation in working environments in the hot-humid climate of Rio de Janeiro. Highlighting the key qualitative and some specific quantitative outcomes, this paper summarises the winning scheme, from Zanettini Arquitetura S.A., co-authored by Arch. José Wagner Garcia and a team of consultants, including the Environment and Energy Group of FAU-USP.

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1. INTRODUCTION

In 2004 the Brazilian Petroleum Company, Petrobras, organized a design competition involving four national architectural practices for its new research centre, CENPES II, encompassing over 100,000m² of construction by the Guanabara Bay in Rio de Janeiro, Brazil (e.g. fig. 1). The programme of activities is an extension of the existing research centre, CEMPES I (attached to the site of the design), to serve basically the following functions: laboratories, offices, convention centre, restaurant, warehouses and other special facilities (i.e. energy generation and model testing of petroleum platforms).

The competition brief asked for design strategies such as buildings’ site planning, architectural form, building materials and window wall ratio, related to environmental comfort and energy efficiency making maximum use of daylight, natural ventilation and vegetation. Issues of sustainability were also highlighted in a broader sense, such as water consumption and the environmental impact of building materials, regarding aspects of life cycle analysis.

Following principles of environmental design, the winning scheme from Zanettini Arquitetura S.A., co-authored by the Arch. José Wagner Garcia, supported by a team of consultants, including the Environment and Energy Group of FAU-USP, was strongly influenced by the local hot-humid climate (e.g. fig. 2). A horizontal architectural composition was planned according to solar orientation, natural ventilation and external views, in which buildings are connected by transitional semi-opened spaces. Double roofs, shading devices, shallow plans and light thermal mass were proposed as architectural features to respond to the environmental conditions. Some of these strategies are seen in the prime examples of the local modern architecture, developed between 1930 and 1960.

The search for the environmental strategies started at the conceptual stage in which the design process was informed by principals of buildings’ physics and analytical studies, including thermal, lighting, acoustics and energy matters. The winning scheme represents a major conceptual and technical contribution to the development of new paradigms, considering a more “environmentally friendly” architecture in Brazil. The design proposal for the Petrobras’ new research centre in Rio de Janeiro, brings about the discussion of sustainability to the context of the contemporary Brazilian architecture, within a comprehensive approach including the application of advanced simulation tools, which are already familiar in referential projects of the international scenario.

CENPES II gathered over 140 professionals of complementary backgrounds in the field of building design, within a design time of ten months (from...
Environmental Design for Petrobras: A Step Forward in Brazilian Architecture

November 2004 to September 2005). The start up of the construction is due to the end of 2005 and the partial completion of the scheme, with offices, part of the laboratories and the convention centre, planned to be ready for occupation in the first semester of 2007.

Due to the extension of the environmental studies and the complexity of the methodology applied for the development of the analytical investigations, this paper presents an overview of the environmental studies, touching on some of the main design decisions and the consequent results, sparing many of the technical details, in an attempt to clarify the relation between the architecture and the environmental strategies.

2. DESIGN CONCEPT AND LOCAL CLIMATE

The design proposal responds to the challenge of “environmental friendly” architecture by creating internal, transitional and external spaces which are favourable to the users’ environmental comfort, the energy efficiency of buildings and the incorporation of landscape in the architectural compositions within and in between buildings. The possibility of energy generation through photovoltaic panels is also integrated in the design, and drove specific design decisions of one of the main buildings. As mentioned before, the local climatic conditions were extremely influential in the design process, going from the definition of site planning and architectural aspects of the buildings, to the establishment of environmental performance criteria, such as comfort zone and set points to internal temperatures.

The predominantly horizontal composition is formed by buildings intercalated by transitional spaces, with open and covered areas environmentally enriched by landscape design and the consequent creation of shadowed outdoors spaces. These principals are highlighted in the lifted office building (called central building), the rows of laboratories and the circular conventional centre (e.g. fig. 3).

Preliminary analyses of the local climate showed the importance of shadowing and ventilation as potential passive means for the thermal comfort indoors and outdoors, because of the hot-humid conditions all year round. Based on that, the environmental approach starts from the treatment of the buildings’ immediate surroundings. Hence, roofs, facades and landscape have a fundamental role in the concept of both internal and external spaces, mediating the extreme external conditions by blocking solar radiation and rain without compromising the benefits of daylight and natural ventilation.

With special concerns to the internal spaces, thermal insulation and light thermal mass were added to the shadowing and ventilation means, with the objective of minimising external heat gains. With regards to daylight, this is characterised in the design by two complementary strategies: the “filtration” of direct sunlight through external protection and vegetation, which is then reflected towards the inner spaces as diffuse light, and also by the maximum access of the diffuse daylight.

The environmental design of the buildings that constitute CEMPES II, with respects to thermal and energy issues, was developed according to two main objectives. The first one is the maximum use of passive strategies for internal environmental control, when the external climatic conditions are favourable. The second one is the minimum energy consumption during the times of the year when the external conditions, added to the occupation’s heat loads, require the use of air conditioning.

Based on environmental principals and guidelines, the site planning of the buildings prioritises the north-south orientation to the rows of laboratories (e.g. fig. 3). This disposition substantially reduces the buildings’ exposure to direct solar radiation at the same time that it creates appropriate conditions for photovoltaic panels on the roofs. To the benefits of natural ventilation, the series of parallel linear blocks facing north and south is also beneficial to the permeability of the predominant winds (south-east and east).
The site planning of the other buildings of the complex follow other criteria which are complementary to the solar and wind orientations. The central building (e.g. fig. 4), destined to offices in a slab building form, for instance, is lifted above the height of the laboratories, facing east and west, benefiting from the view of the sea, crossing the linear formation of laboratories on the ground floor (e.g. fig. 5). Besides the view of the sea, the incident of predominant winds on the buildings’ envelop is also privileged. Likewise, the circular form of the convention centre (e.g. fig. 2), with a void in the middle and openings on the ring-form, and the other buildings, which follow a warehouse and industrial building type, are part of a masterplan that allows natural ventilation and daylight around the buildings. The issue of direct solar radiation is dealt with in the design of the buildings’ envelop, with specific protection devices.

In the buildings characterised by big internal volumes because of their specific functions, sheds were combined with openings at lower levels to provide staff effect ventilation and daylight. Because of the relation between the directions of the prevailing winds and the solar orientation, the ventilation strategy was separated from the daylighting the design of the shed-roofs.

In terms of structure, the solution was a mixed system of steel and concrete, which did not compromise the environmental approach. On the other hand, the specification of materials and buildings’ envelop involved a series of analytical studies to assess issues of environmental performance. As a result, the floors were specified in concrete slabs with internal insulation, whereas the facades were in light concrete with internal and external insulation, the internal partitions in drywall, the windows in transparent single glass and the top openings of the sheds in green glass.

3. ENVIRONMENT AND MASTERPLAN

The understanding of the microclimatic conditions implied in the elaboration of a detailed data bank, followed by studies of solar geometry and ventilation in the masterplan scale. These three complementary studies were determining for the establishment and testing of the buildings’ environmental strategies, including site planning and buildings’ orientation. The analysis combining the climatic data with the studies of solar geometry and ventilation also contributed to the landscape design and to the evaluation of comfort in the open spaces.

3.1 Climate

The climatic study was based on the elaboration of a data bank for the area of the design, based on records of air temperature, humidity, radiation and wind from the last five years, obtained from the meteorological station of the city’s international airport (close to the site). The elaboration of this bank was directed by the purpose of creating a reference year, added to the identification of the most critical summer month and the definition of a reference summer day.

These three outcomes of the climatic data bank were used to the analytical studies of environmental performance, considering the passive and the active means of environmental control of buildings. With regards to temperature and humidity, the reference year was then based on hourly averages from 2000 to 2004 (included), containing 8,760 hours. Wind data was also considered hourly, referring to the prevailing direction, southeast (SE).

Regarding the critical summer conditions, February 2003 was pointed out as the worst case. Within this month a period of stability was identified for the definition of the reference summer day, which was the 9th. Each of the three outcomes of the data bank had a specific purpose within the environmental studies. The reference year was mainly used for the studies of potential for natural ventilation, the critical summer period was major for the calculations of peak loads for the air condition and the reference day was to support in-depth analysis of the environmental performance of buildings’ materials and components within a 24 hour cycle. In summary, the overall evaluation of the climate showed the need for design solutions which deal with the harsh conditions of high temperatures and high humidity rates, showing RH values higher than 70% in 66% of the year.

3.2 Solar Geometry

To assess the impact of solar radiation upon the buildings’ masterplan, three types of solar geometry studies were carried out: 1. shadows created by the buildings; 2. sky views from windows and sheds; 3. amount of incident solar radiation upon the glazed surfaces. As a result, it was possible to see that, for instance, the open spaces between the rows of laboratories receive direct solar radiation for most part of the summer days, in the absence of vegetation. In general, however, the shadow analysis proved that there is no significant influence from the buildings on each other. One of the few moments when the impact between buildings can be seen is at 7.00am, when the lifted office block casts its shadow over the west wing of laboratories. (e.g. fig. 6), which was taken as a positive aspect of the masterplan, once that daylight can be explored and the solar protection is solved in the design of the buildings’ envelop. The combined analysis of these three different studies provided detailed information for the assessments of daylight in the inner spaces as well as for the quantification of the impact of daylight and incident solar radiation in the thermal performance of buildings.
3.3 Ventilation in the open spaces

The studies about natural ventilation around buildings had the purpose of getting visualization and quantification of wind velocity around buildings and pressure upon the buildings’ envelop. The results of such studies were used for the assessment of environmental comfort in open spaces and natural ventilation inside the buildings. For the analytical studies using the CFX software it was established that the mean annual wind speed is 3m/s, coming from southeast. Due to the interest in wind behaviour at the pedestrian level, the simulations considered the height of 1.5m. The height of 10m was also verified to get wind data at the windows of the lifted office building, i.e. the central building.

The results showed wind velocity at the pedestrian level varying between 0 and 1m/s, occasionally reaching the mark of 1.5m/s in the open spaces (patios) between the rows of the east wing of laboratories, which are the main areas destined for people’s circulation and outdoor resting and pause (e.g. fig. 7). In the west wing of the laboratories higher wind speeds were registered, caused by the influence of the lifted slab-like office block. As a consequence to that, the natural ventilation around buildings contributes, in a great part of the site, for the thermal comfort in the open spaces and also in the internal spaces, such as in the office cells attached to the laboratories’ rooms. At the height of 10m around the office building, the wind velocities registered were between 1.0 and 2.0m/s. These figures had a major role for the satisfactory thermal comfort at the open terraces, located at the top of the building.

3.4 Environmental comfort in the open spaces

For the calculations of environmental comfort in the open spaces the index of Effective Temperature for internal spaces, added to solar radiation and wind velocity. Keeping the data about air temperature and relative humidity and changing the conditions of exposure to solar radiation and wind, it created nine possible scenarios of microclimates in open spaces: Regarding the assessment of comfort in open spaces, three different areas were selected: the central void of the convention centre, the patios between the rows of laboratories and the terrace of the office building. The selection of these areas was based on the duration of occupancy and type of uses and activities proposed in the design.

In the first area, the void of the convention centre, considering exposure to solar radiation, the hours of thermal comfort are approximately 50%. However, with protection against the total incident solar radiation it is possible to reach up to 85% of comfort hours. In the patios between the laboratories, where wind velocity is significantly lower, when added the impacts of solar radiation on the annual percentage of comfort hours is relatively lower, marking 13%. This figure goes up to 23% when solar radiation is blocked. On the other hand, in the areas of the patios where the wind velocity is higher, even with the impact of solar radiation, the hours of comfort are increased to 67.5%. If a shadowing effect is added to that, the percentage goes up to 98%.

For the terrace of the office buildings (figure 2), two options were tested for the top roof: one of metallic cladding (with thermal insulation), blocking all the sun, and another of perforated metal. Initially, the metallic cladding offered a longer period of comfort (77%) rather than the perforated metal (64%). Nevertheless, it has to be considered that in the second case, with the addition of more localised shading strategies under the perforated metal roof and closer to the area of occupation (for instance, with the incorporation of vegetation or canopies) the percentage of hours of comfort is similar to the first case (75%). Besides, it is important to highlight that the sense of enclosure caused by the opaque metal roof is likely to play a subjective negative impact upon the people’s perception of the environment, when compared to the effect of the second option, that filters light and air and allows the occurrence of sun patches along the extension of the terrace. Overall, the three areas in the project taken as case studies for the assessment of thermal comfort in the open spaces of CEMPES II proved to be satisfactory, since the proper landscape strategy is provided.

4. ANALYTICAL STUDIES

4.1 Environmental performance and thermal comfort

Regarding the environmental performance and the related thermal comfort issues, the buildings’ design had different strategies and objectives depending on the distinct requirements of the different uses. In the offices and restaurants, for example, the objective was the optimisation of the design for energy efficiency of the active system (air condition), however, still considering the potential for natural ventilation, including night-time ventilation. Therefore,
in such spaces the concept of the mixed-mode strategy for environmental control was introduced. As seen mainly in European references, the mixed mode strategy is justified by the savings in energy consumption and the users’ contact with external conditions. In the laboratories and convention centre, the particularities of the use demanded total artificial control of the internal environments. For this reason, as in the previous situation (offices and restaurants), the emphasis of the design concerning its thermal performance was on the energy efficiency of the air condition. Finally, in the buildings of big volumes and shed roofs, where the warehouse and industrial typology were developed, the strategy was to maximize the hours of comfort relying completely on the efficiency of the design for passive strategies, such as insulation, solar protection and mainly and foremost natural ventilation.

Having said that, the assessment of thermal comfort in the internal environments was carried out based on two different parameters, defined accordingly to the main mode of environmental control (natural or artificial). For the use of natural ventilation, the adaptive model was adopted, in which the comfort temperatures (TC) vary in accordance to the external ones. It is worth noting that the adaptive model was applied in internal spaces totally reliant on natural ventilation and also on the other environments, such as the offices, to assess the periods of passive means within the mixed-mode strategy. In this model, it was verified that 10% of the people were dissatisfied from internal Effective Temperatures (ET) between (TC-2.5°C) ≤ ET ≤ (TC+2.5°C). For Effective Temperatures between TC±3.5°C, the percentage of dissatisfied people goes up to 20%. In the offices the threshold of 10% of dissatisfied was established to limit the use of natural ventilation, whilst in all others it was accepted 20%. For the fully air conditioned environments, the set point conditions of 26°C with RH of 65% were recommended (in compliance to the national regulation NBR 6401, ASHRAE 55 and ISO 7736).

4.2 Daylight performance

With respect to daylight, the alternative solutions assessed throughout the design process considered the optimum results balancing thermal and lighting buildings’ performance. This refers to decisions about orientation, type of glass and solar protection devices of windows and sheds. The recommendations contemplated green glass for the roofs’ openings and transparent glass for windows. The daylight evaluations revealed that a great part of the internal spaces, where daylight is permitted without restrictions, is well served by daylight.

With special regards to the laboratories, a reasonable and even distribution of lighting levels was found, due to the influence of solar protections in the windows, which allow the access of diffuse light at the same time that they provide reflection of direct light to the interior as diffuse light (e.g. fig. 12, 13). However, in these same spaces, complementing daylight with
artificial light proved to be necessary on specific working areas.

Figure 12: Studies of shading devices for the laboratories to maximise penetration of diffuse light.

Figure 13: Distribution of daylight factors in the laboratory's room.

In the central building, with the objective to improve the daylight conditions in the office environments, a series of shading devices were analysed for the east and west orientations. According to the analytical studies, the levels and the distribution of daylight were favoured with the implementation of appropriate solar protections. As a consequence of such elements, the average daylight levels in the east wing of office spaces reaches 315lux, at the same time that the diffuse daylight can access parts of rooms at the opposite end of windows, therefore, substantially improving the distribution of daylight.

5. CONCLUSIONS

The relevance given to the environmental issues already in the competition brief ensure a significant potential in terms of performance. With concerns to the design process, it is worth mentioning that advanced simulation tools such as CFX and Radiance were applied in the evaluation of the design, constantly contributing with recommendations including specifications and architectural adjustments.

The initial compromise with specific issues of environmental impact led to the interest of Petrobras for the certification of CENPES II as an example of green design. For that purpose the LEED system was chosen (Leadership in Energy and Environmental Design) by the Department of Energy of The United States. In order to respond to the requirements defined by the LEED, the design was monitored and therefore constantly informed about its potentialities and impacts throughout its development.

It is known that the differences between the Brazilian and the North American environmental contexts, varying from climate, building regulations to market aspirations, are likely to incur in inconsistencies towards the LEED's requirements and the true value of this certification in the case of the CENPES II. Nevertheless, the application of LEED's methodology has its value for the pioneering exercise for buildings' sustainability assessment in Brazil.

Petrobras' new research centre in Rio de Janeiro definitely represents the first grand public initiative towards environmental improvements in the field of building design in the country, bringing a step forward in Brazilian Architecture. However, the developing process of such environmental design was also marked by barriers, which were mainly three: the appropriate choice and the application of computational tools, the understanding of the environmental performance and advantages by specialists of the complementary design team and, finally, the culture of artificial environment. On the other hand, in this specific case, initial capital costs and architectural pre-conceived ideas were not arguments against the evolution of environmental aspects in the design.

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