An energy efficient office building in a tropical climate: The INPE-CRN's Project in Natal, Brazil

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This paper presents the design development of an energy efficient office building in a tropical climate. The design decisions are based on the architects and consultants previous experiences, recommendations from scientific literature and computer simulation tools, since the early stages of the design process. The simulation tools focus on shading design, natural ventilation behavior, natural lighting design and energy analysis. The building design was developed in the LABCON-UFRN (Environmental Comfort Laboratory in the Rio Grande do Norte Federal University) and it aims to attend their occupants' requirements and to promote architecture practices related to energy efficiency in buildings. The analyses show that design decisions are major determinants to achieve an energy efficient building in terms of energy use. The resulted design adopts a contemporaneous architecture language, which is sensible to the local climate, to be built in the Regional Campus of the National Institute for Space Research – INPE-CRN in Natal, Brazil.

Keywords: energy efficiency, office building, tropical architecture

1. INTRODUCTION

This paper aims to present a design process experience that resulted in an energy efficient low-rise building project: the head office building of the National Institute for Space Research – regional administration for Northeast. The INPE-CRN building project was initially developed by volunteer researchers from the Environmental Comfort Laboratory in the Rio Grande do Norte Federal University (LABCON-UFRN), for research purpose. Afterwards, a local architecture office was contracted to keep the development. The main goal was to create a reference for tropical climate office buildings, integrating researchers with practitioners, providing a didactic experience and reinforcing the importance of partnership of local institutions.

Figure 1: Site location.

The building project was based on bioclimatic principles and low cost strategies toward energy efficiency in buildings. Its development was guided by established recommendations for building design in tropical climates, team design expertise and use of building simulation tools.

The site is located in the city of Natal, Northeast coast of Brazil (5.5°S; 32.2W), **Figure 2**.

Figure 2: City location: Natal, Brazil.

2. INTEGRATION OF METHODS AND TOOLS TO THE DESIGN PROCESS

The design process managed to produce an efficient energy project and provide a case study. Therefore, the actions were assessed in terms of energy performance.

The team members focus for such criterion occurred spontaneously during the whole process because the majority of them are researchers in this field. Furthermore, the energy and environment comfort concerns were discussed from the first meeting until the end of the detailed phase, and the most influential design issues were identified since the first team meetings. The decisions were taken by common agreement, although the team members were very well defined in their activities.

The main stages of design process relate to the RIBA Plan of Work [1] were: pre-design, sketch design stage, detail design stage and final evaluation. The energetic approach is similar to the structure introduced by Szokolay [2], **Table 1**. Each stage corresponds to a task, which demands specific information and tools, to deliver one or more products.

Table 1: Energetics in design, adapted from Szokolay [2]

Stage	Task	Information	Tools	Product
PRE-DESIGN ANALYSIS	Digest brief Identify constraints Study climate Define 'solution space'	Climatic data International energy standards Precedents	Bioclimatic analysis [3] Previous experiences with simulations [4] Recommendations [5]	Performance specification Energy target 'if...then...' type Guidelines
SKETCH DESIGN STAGE	Generate ideas Formulate and test design hypotheses	Knowledge of thermal effect of shape and form, of thermal behavior of materials Evaluation criteria	Test simplified alternatives [6] Refine specific solutions [7]	Design proposal Alternatives
DETAIL DESIGN STAGE	Make all detail design-decisions: fenestration, shading, dimensions, envelope materials	Awareness of energy consequences of detail decisions	Special purpose tools: Thermal [6] Lighting [8] Daylighting [9] Natural ventilation, CFD [10]	Refinement Selection of alternatives
FINAL EVALUATION	Total energy and thermal performance in detail	Precise data on materials and occupancy	Detailed modelling in a comprehensive tool [6]	Final energy budget

2.1 Pre-design

Pre-design phase and program establishment took several months, which resulted from these main tasks:

- several interviews with future building users, to identify demands, and with managers, to identify constraints;

- meetings with future users, designers and consultants, to expose and introduce alternative ideas in relation to the conventional ones;

- functional site assessments, to pre-select the most potential sites.

The bioclimatic assessment has been done many times in the past for other studies. Considering the minimum influence of the other buildings, the assessment was based on TRY weather file from the local airport climate data [11].

Firstly, the climate is predominantly hot and humid. Most of the time, the thermal comfort can be achieved through natural ventilation (Figure 5). The wind is regular during whole year and the air speed is always enough to be considered as a strategy to reach comfort and to remove thermal loads from buildings (Figure 4). Indeed, the local knowledge confirms this analysis.

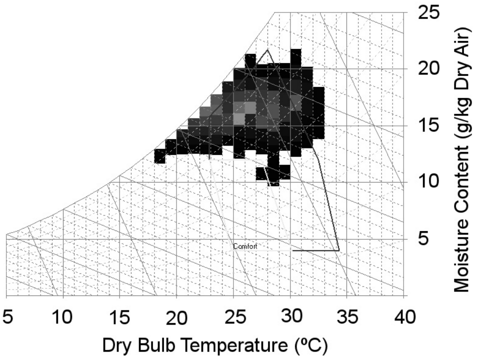

Figure 3: Psychometric assessment with adaptive thermal comfort zone [12] and potential use of ventilation [12, 13]

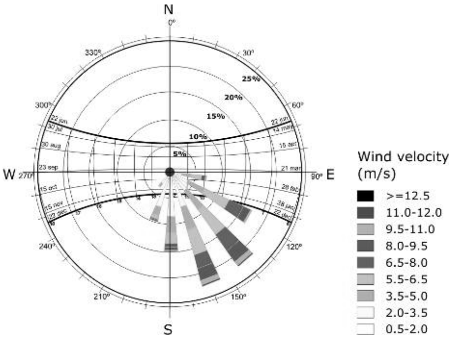

Figure 4: Sun-path diagram and wind rose for Natal, Brazil [14].

Secondly, passive solar heating of other form or thermal loads is highly undesirable and shading is necessary. Natal geographic localization (Figure 4) and its sky characteristics contribute to the high incidence of solar radiation. Incidence on North façade can reach 457 Wh/m², 832 Wh/m², for East, 569 Wh/m² for South, 884 Wh/m² for West and 1,075 W/m² for horizontal surface (Figure 5).

This first phase resulted in guidelines to support the sketch phase, as organized in Table 2.

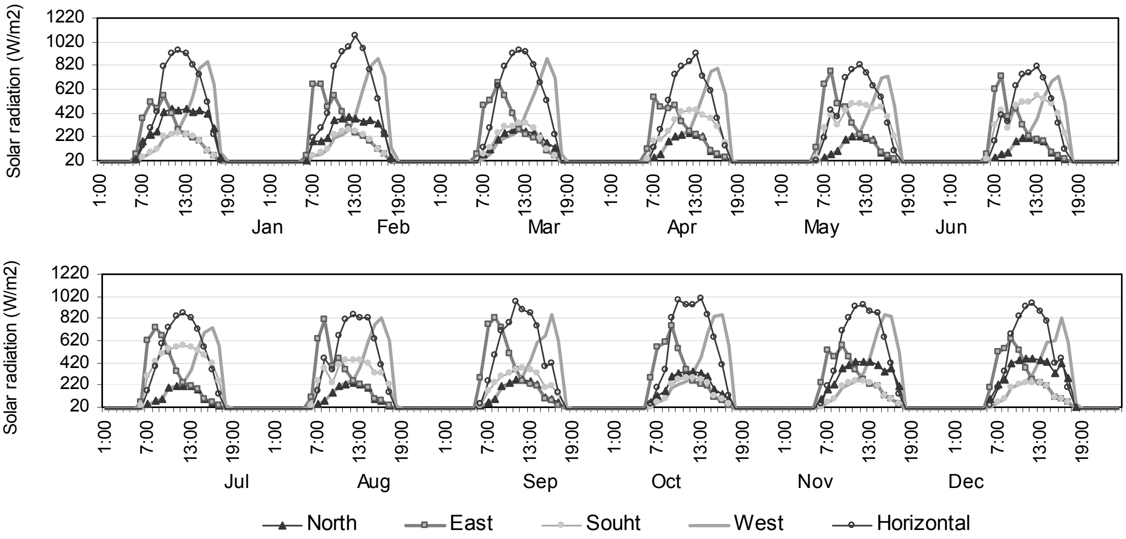

Figure 5: Hourly solar radiation on five main surfaces

Table 2: Energetic guidelines resulted from the pre-design phase

Strategy	Goal	Design impact
envelope: exposed area, U-value and thermal absorptance	thermal load reduction	plan roof, light colours, insulation
shading	direct solar gains reduction	low depth plan, orientation, shading devices
natural ventilation	hybrid use with air conditioning	low depth plan, open lay-out, cross ventilation, window orientation
microclimate	reduction of temperature and thermal radiation	sustainable landscape
individual control of air conditioning and artificial lighting	to incentive the use of higher cooling set-point, natural ventilation and daylighting	lay-out, free-running corridors, buffer zones

2.2 Sketch phase

The development had emphasized the building orientation and form in order to avoid excessive solar heat gain and to explore natural ventilation and lighting (Figure 6). The building envelope was designed to minimize the thermal loads without compromising the wind and diffuse light, and to promote integration between occupants and the exterior space. The building orientation relative to prevailing wind directions, the cross-ventilation promoted by openings positioned on windward and leeward façades and operable window equally permeable to wind passage contribute to increment the potential use of natural ventilation. Thus, a longitudinal volume was conceived with 15° of azimuth (main façade). The largest facades were faced North and South to prevail wind from Southeast. The East and West facades were kept blank to minimize the thermal gains.

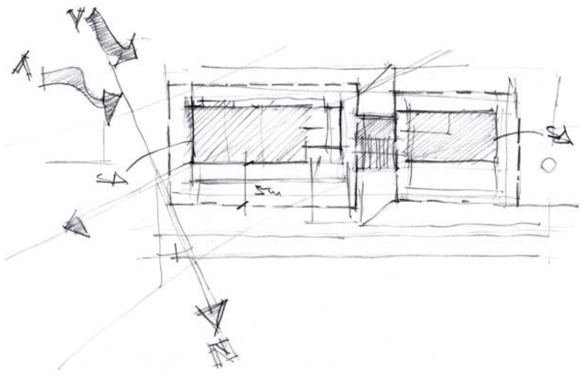

Figure 6: Floor plan sketch.

The potential of shading increased with the long eaves (Figure 7) and horizontal shading devices

(Figure 8), providing shading most part of day. Shading device solutions developed naturally. The study of these elements started even before the definition of the volume. Such approach was optimized with the software SunTool demonstration version [15].

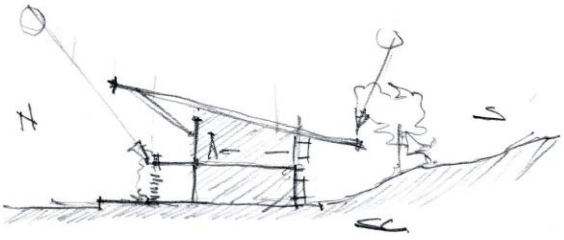

Figure 7: Section sketch.

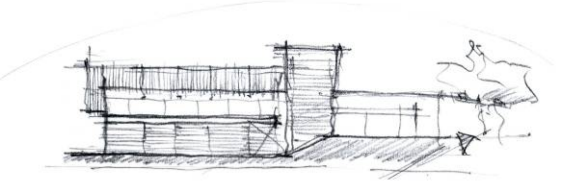

Figure 8: Front view sketch.

Seeking to guarantee visual comfort and satisfactory levels of luminance in work environment the building design emphasized building form, opening typology with use of glass in the upper parts of windows and doors, light colors in internal wall and ceiling surfaces.

2.3 Detail phase

The detail phase simulations aimed to improve the analysis accuracy. Shading, natural ventilation and lighting analysis were carried out to test previous theories, to assess the energy performance of the design and to refine the project.

At this stage, the design proposal was characterized by a longitudinal form interlaced by two blocks: block 1, block 2. Between them there is a water tower where is also located a stair and a lift to provide accessibility. The office rooms are in block 1, distributed in the first and second floor. In block 2, above slope, takes place a multi-purpose room, with a small coffee area. The presence of two sloped roof in block 1 and 2, with large eaves and the horizontal shading devices in facades North and South, are another noticeable aspects of building form.

Figure 9: Perspective of INPE-CRN building.

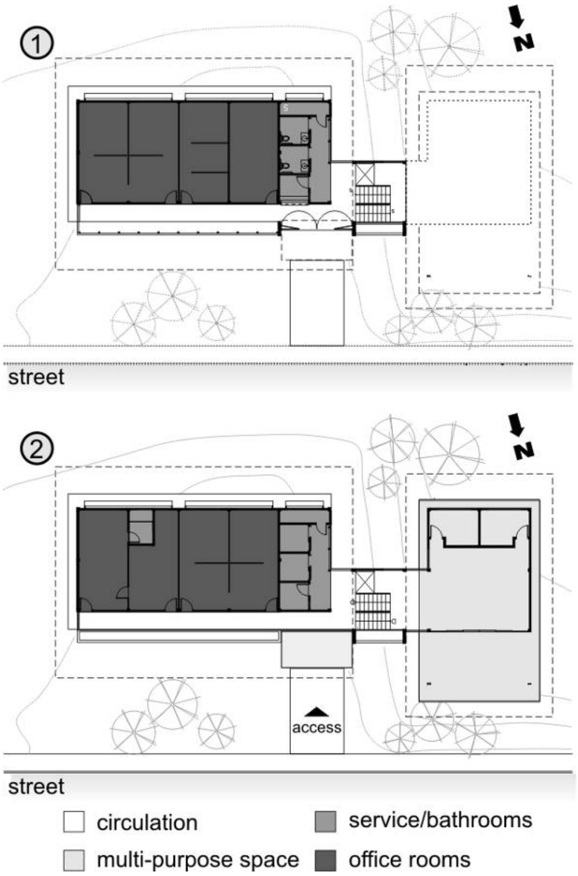

Figure 10: Floorplans with zoning: (1) ground level and (2) second level

2.3.1 Shading design and evaluation

The analysis was carried out using Ecotect v5.2 to detail the dimensioning of shading devices. The analysis showed that openings in working spaces, block 1, were shaded about a range of 80% of the time. The East and West facades, which are blank, are shaded during a long period of the year by a neighbor building, land topography and eaves. Trees are planned to improve shading in West facade where they do not act as wind obstructions.

2.3.2 Natural ventilation

The CFD analysis was executed on PHOENICS 3.6 platform, restrict to the prevailing direction of 150° and mean air velocity of 4,6m/s. The mainly objective was to assure that a pre-existent building beside of the proposed building should not influence.

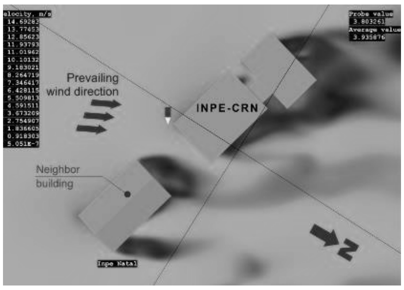

Figure 11: Wind site analysis using CFD.

2.3.4 Natural lighting

The analysis was made in the software Radiance Desktop v2.0 Beta and a representative office room floor was simulated. The simulations occurred considering one day in 21/Jan and 21/Jun at 08:30h and 16:00h. The results showed values above 500 lux, the minimum recommended to office environments that testify the design decisions.

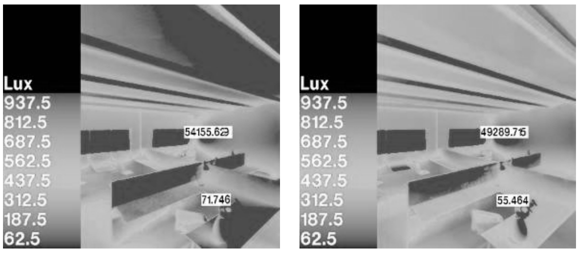

Figure 12: Natural lighting simulation of office room in 21/jan and 21/jun at 09:00h and 17:00h.

2.3.5 Artificial lighting

At this point, a pre-dimensioning of lighting fixtures was done using the software E2 [8]. The lighting power density was of 11.8 W/m², using T8 luminaries. The luminaries must be arranged in lines parallel to facade with independent activation in order to take advantage of natural light.

2.3.6 HVAC System

The air conditionings were dimensioned through simulations on VisualDOE 4 [6]. The models were selected based on the EER (energy efficiency ratio) and cost of the equipments. Considering the little difference of cost, the selected ones were the most efficient of the market, varying from 2.98 to 3.51 EER.

2.3.4 Thermal analysis

The analysis did not use thermal simulation at this stage because the system construction were defined with base on a LABCON´s current research project, which deals specifically with the subject (Table 3)

Table 3: Main envelope building material and thermo-physical properties

Use	Material	U-value (W/m².K)	Absorptance (%)
Roof	Roof sandwich panel with EPS	0.96	10
Wall	Cellular concrete panel	2.50	20
Floor	Concrete slab on ground	2.04	-

Use	Material	U-value (W/m².K)	SHGC
Window/ Door	Single clear glass 6mm	5.7	.884

2.4 Final phase

Due to the absence of an energy target to contextualize the achievements, the final design proposal was compared with hypothetical combinations of architectural design and building service (**Figure 13**). The efficient design (architectural and building service) allowed saving 49% in relation to a correspondent building with ordinary design. The energy saving exclusive for an efficient architectural design is 34%, considering a base case with efficient building service.

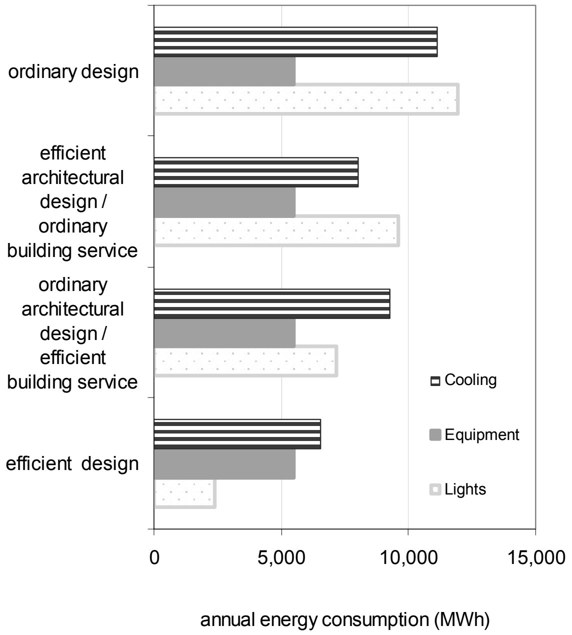

Figure 13: Energy end-use performance of different combinations of architectural design and building service.

The other major influences were the use of daylighting, ordinary constructive systems and shading devices (Figure 14). Daylighting had saved 33% of total annual energy consumption, shading devices had saved 24% and better constructive systems had saved 16%, while the energy demand was 30%, 24% e 19%, respectively.

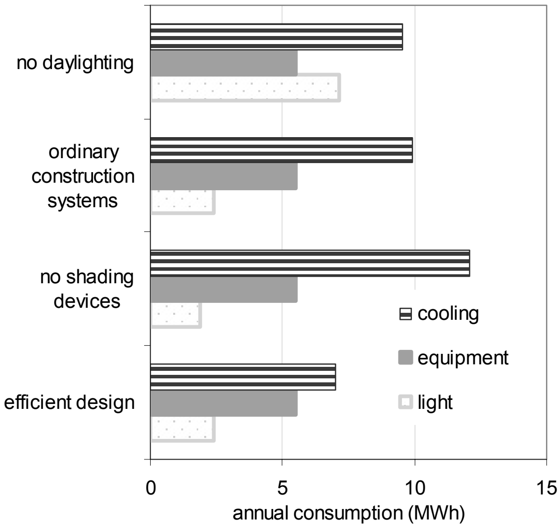

Figure 14: Energy end-use for major design decisions.

3. CONCLUSIONS

The efficacy of the first design decisions were confirmed and refined during the other process stages. Although they were based on well known knowledge, best practices and previous experiences, the client allowed a high level of freedom to make the best choices as possible since the beginning. For example, the orientation, building volume, lay-out and some facades characteristics were decisive.

Comparing the “final phase” simulations with the importance attributed to the main design decisions (Figure 15), the early decisions were the most important ones.

Very few simulations occurred at the early stages because there were not necessary. However, the results of thousands of simulations from previous researches [4, 16] were influencing the team members, indirectly. In one hand, tools such as Ecotect [7] and VisualDOE [6] had demonstrated potential to support the team members, making some concessions to the their experience. Shading design, indoor temperature estimation and thermal loads to HAVC system dimensioning were the major contribution of these softwares. On the other hand, daylighting and CFD tools should be friendlier to make them more integrated to the design process.

The INPE-CRN building project is becoming an example of good practices with a second place award of the Rational Energy Use Competition, promoted by the Energy and Mine Ministry (MME) of Federal Brazil Government. The INPE-CRN building is to be constructed late in 2006.

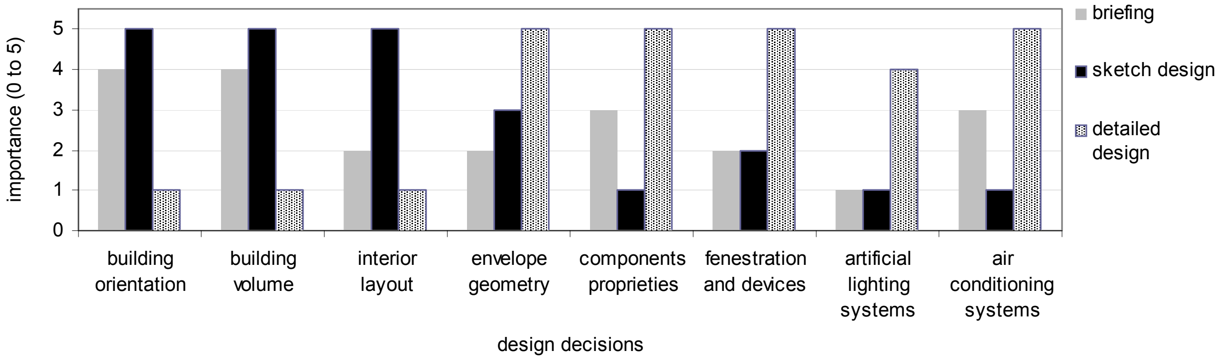

Figure 15: Importance of design decisions during the design process.

4. ACKNOWLEDGEMENT

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