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Nearly Zero Energy Building (NZEB)

Materials, Design and New Approaches

Edited by David Bienvenido-Huertas

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Contents

Chapter 5

An Integrated Design Process in Practice: A Nearly Zero Energy Building at the University of Brasília - Brazil

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Abstract

This study aims to present the design experience of LabZERO|UnB, an NZEB building awarded in a public call, that will be built on the University of Brasília campus. The method consisted of defining the design team and the Integrated Design Process (IDP), establishing assumptions and design guidelines, schematic design, initial computer simulations, design development, new simulations, and final calculations for the synthesis of energy performance. As a result, IDP proved to be efficient and underlined the possibility of translating research experiences into practice. The barriers and potentialities related to the coordination of a multidisciplinary team stand out, likewise the organization, planning, and achievement of goals. In the design concept of the 200m^2 building, the basic assumption was the adequacy of the architecture to favor the use of passive resources, respecting the local climate, classified as high-altitude tropical climate. Moreover, bioclimatic strategies were used, such as the North/South orientation of main façades, narrow floor plan, limited window-wall ratio, and adequate construction materials, to optimize energy consumption. As a result, the distributed generation of electricity was estimated at 58.29 kWh/m^2. a year and the final electricity demand was 34.29 kWh/m^2. year. Hence, this process indicates the real possibility of reaching the zero energy balance.

Keywords: nearly zero energy building, integrated design process, computational simulation, PV energy

1. Introduction

Buildings are a central part of the transition to a low-carbon society, with less environmental impact and energy efficiency, as they are responsible for consuming 32% of all energy generated in the world. This is equivalent to 19% of greenhouse gas emissions [1], in addition to consuming 50% of all raw material extracted by human action [2]. Initiatives such as the Sustainable Development Goals (SDGs) of the United Nations (UN) [3], the New Urban Agenda [4], and the Paris Agreement [5] point to the need for the reduction of energy consumption in buildings, generation of clean energy and more sustainable cities and communities to mitigate climate change and environmental crisis.

Buildings with zero energy balance, also known as the term Zero-Energy Buildings (ZEB), have an equivalent demand and generation of renewable energy within a year [6]. However, the equivalence between consumption and generation is not enough, because it is essential to achieve a demand reduction. For this, conservation and energy efficiency strategies are needed from the preliminary design [7], since they also provide thermal and lighting comfort, in addition to minimizing the environmental impact of the building in its operating phase. This includes integration with passive strategies, particularly in terms of natural lighting and ventilation, and high-performance enclosures. According to [8], new buildings have the potential to reduce energy demand by 50% if compared to the traditional ones, only by adopting commercially available energy conservation and efficiency strategies.

Thereby, the idea of NZEB emerged in the 1990s and afterward became part of energy policies in several countries. In Europe, the EU Directive on Energy Performance of Buildings [9] set goals to turn all buildings nearly zero-energy by 2020. The US Department of Energy's Building Technologies Program established similar objectives: achieving zero energy homes by 2020 and zero-energy commercial buildings by 2025 [10]. In addition, this building category is aligned with the 7 and the 11 UN Goals of Sustainable Development. According to O´Brien et al. [7], the NZEBs are characterized by a rigorous design and operation of the building as an integrated energy system, with a good indoor environment suited to its role. Some key points are mentioned, such as: an integrated approach to energy efficiency, passive and active design and building operation; optimization of solar collection, requiring building design and roofs used for conversion to electrical energy, useful heat, and natural lighting. **Table 1** shows the difference in project design and operation between conventional buildings and NZEB buildings.

In Brazil, there is still no regulation regarding NZEBs, but specific actions have been taken to leverage the improvement of energy efficiency in buildings, through regulations and standards [11], building performance [12], and distributed energy generation [13]. However, concrete actions for the construction and monitoring of NZEB buildings are recommended to enable the dissemination of the concept. In this context, the National Program for Energy Efficiency in Buildings (Procel Edifica) carried out a Public Call in 2019 to support the construction of up to 4 (four) NZEB's in strategic locations throughout the country [14]. The objectives of the call included: to foster knowledge, research, and development of NZEB project designs; to create a demonstration effect of NZEB buildings, enabling large-scale adoption, and, finally, to verify the technical and financial feasibility of the construction and operation of NZEB buildings. The Public Call was launched on December 2nd, 2019, and the deadline was set to February 20th, 2020. The call requested the submission of the Basic Project Design of the NZEB new construction or to undergo retrofit, bringing

Design and operation of building systems	Conventional buildings	NZEB buildings
Building envelope's materials	Passive, not designed as an energy system	Optimized in passive design integrated with active solar systems
Heating and ventilation air conditioning (HVAC)	Large systems, oversized	Optimized small HVAC systems, integrated with solar systems, combining heating and power, seasonal storage, and district energy
Solar systems / renewable energy technologies (RET)	No systematic integration – an afterthought	Fully integrated: natural lighting, solar thermal, photovoltaic, hybrid, geothermal, biofuels integrated with smart microgrids
Building automation systems	Building automation system not effectively used	Building Controls for optimizing performance
Design and operation	Design and operation are considered separately	Fully integrated and optimized design and operation, considering environmental comfort

Table 1.
Design and operation of NZEB buildings versus conventional buildings.

together "the elements that define the building, aiming at the accuracy of its basic characteristics and its desired performance in the work, with the estimated cost and execution time" [14].

The University of Brasília (UnB) has been investing in strengthening sustainability actions on its campuses; according to Taucher and Brandli [15] (2006) "the socio-environmental dimension, in this context, stands as a principle for institutional development". Thus, the construction of a zero-energy balance building and possibly replicable typology proves to be an important step towards the dissemination and consolidation of sustainable practices at the University, with positive consequences and impacts even for the city. Therefore, to advance on sustainability purposes, UnB's multidisciplinary team developed a project design for a laboratory and coworking space, called LabZERO|UnB, which was one of the 4 buildings included in the so-called Procel Edifica Public Call (3rd place overall).

This study presents in detail the design process experience of this NZEB building - initially, all design phases, results, barriers, and potential are addressed. Afterward, the final design and the analysis of environmental and energy performance are presented, and the challenges to the implementation of this type of practice, and the relevance of initiatives to promote the dissemination of zero-energy balance buildings, are discussed.

2. Research and design for an NZEB

2.1 Integrated design process of an NZEB building

Note that the characteristic of this type of building involves a project that integrates passive and active systems, in addition to the specification of optimized ventilation and air conditioning systems, connecting natural light and power generation. On the other hand, design practice must shift from a traditional linear process to a collaborative approach between architects, structural engineers, mechanics, electricians, and other professionals. By definition, the Integrated Design Process (IDP) guides decision-making in various professional specialties, including the use of natural resources, energy consumption, and the achievement of environmental quality [7, 10]. Kwok and Grondzik [16] define the IDP as one that synergistically involves several disciplines, to create more efficient and responsible buildings with a lower life cycle cost. Keeler and Burke [10] conceptualize it as a synonym for sustainable design. The authors emphasize that in the case of integrated design, it is important to understand the design variables as a unified whole, involving decisions about energy consumption, natural resources, and environmental quality.

The main features of the integrated project are:

Iterative, non-linear process: In contrast to the conventional (linear) design process, in which team members work in isolation, PPI promotes ever-increasing feedback loops among everyone;

Collaboration and innovation: All participants must share the same vision of the project from the beginning, in order to provide input and feedback to the rest of the team. Project contributors may be asked to work on tasks outside their usual objective. PPI encourages everyone to share the learning and improve the process as a whole;

Multidisciplinary team: Ideally, the PPI includes all stakeholders in a project, and they must be present from the early stages of the work, providing their expertise to the project process. There may be other consultants, depending on the specific needs of each project [7].

These authors mention strategies and aspects related to the design of the NZEB building, by pointing out the design issue and listing the iterative phases of design in **Conceptual Design**, **Project Development,** and **Technical Design**, as shown in **Figure 1**.

Another aspect mentioned by the same authors is related to technical and research matters, in which they highlight the computational model simulation that is going to be used. The importance of research inputs to be applied during the design process is also emphasized. In order words, the development of an NZEB project requires prior knowledge and research, especially in cases of restricted deadlines. Monteiro et al. [17] state that in this type of project, computer simulation has become a mandatory step in the process, adding complexity, but favoring the improvement of the project.

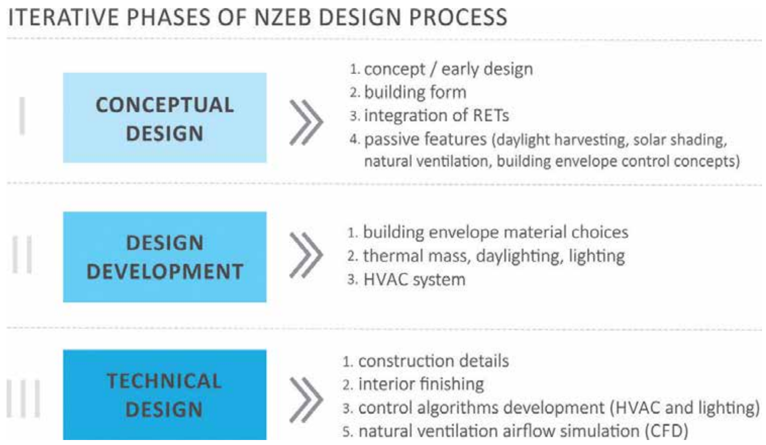

Figure 1.
Iterative phases of the NZEB design process. Source: Adapted from [7].

Mendes and Amorim [18] report an experience of applying the concepts of Integrated Project in a graduate discipline, during which the method proposed by O'Brien et al. [7] was used with two crucial factors: well-defined project objectives shared by the entire team and the presence of a facilitator (coordinator), who sets the tone for collaboration and effective communications during the design process. There was also the creation of teams of specialists in the various themes to be addressed in the project, along with the establishment of periodic meetings with the entire group to share results and align actions. A team specialized in computer simulations acted transversally, receiving and providing inputs to the others. The experience proved to be efficient, noting that the design process reached appropriate fluidity and the project proposed in the discipline achieved appropriate technical results, with an energy consumption lower than its production, reaching the goal of becoming an energy balance building null [18]. This was defined as the basis of the method to be used in the LabZERO|UnB integrated design experience.

NZEB design, monitoring, and benchmarking experiences reported by Garde and Donn [19] present 30 residential and non-residential case studies, grouped into cold, moderate, and hot climates. Three of these buildings can be compared to the conditions of LabZERO|UnB due to the similarities in use and climatic conditions. In these cases, energy demands ranging from 16 to 66 kWh/m^2.year are identified, with energy production ranging from 44 to 115 kWh/m^2.year. In one case, energy production is 7 times greater than the demand. **Table 2** presents energy demand and production data.

2.2 Team definition, initial guidelines, and preliminary design

The definition of the team is an important part of the project conception, as their profile must be able to provide the full development of the products, within the stipulated time limit. It also established the involvement of administrative bodies linked to the project and construction management of the University, as it is a proposal for the construction of a building on the campus, involving bureaucratic issues and administrative actions. Furthermore, the expertise of technicians linked to the university's construction sector is essential for the development of the project in accordance with internal rules. More than that, the technicians carry out theoretical work, resulting from research in the area, and act at the same time in training regarding the bioclimatic project, energy efficiency, etc. This partnership between research and project/action is seen as crucial to leverage more effective actions towards greater efficiency in construction on the University campuses as a whole. In conclusion, there is a need for a mixed team that combines a variety of researchers and professionals from different

Building and location	**Typology**	**Energy demand Kwh/m^2.year**	**Energy production KWH/m^2.year**
ENERPOS- La Réunion (21°S, 55°L)	Offices and classrooms	16	115
Illedu Centre - La Réunion (21°S, 55°L)	Offices	66	92
ZEB@BCA Singapure (1°20 N, 103°L)	Offices and classrooms	40	44

Table 2.
Energy demand and production in 3 NZEBs. Source: [19].

specialties and modes of activity, able to apply the concepts of previous research and work developed by teams of professors and researchers and implement them in the project proposal in an agile way.

Once defining the team, meetings there will be meetings to take preliminary decisions regarding the nature and size of the project, considering budget and deadline limitations. Other decisions taken preliminarily are related to the type of the building (residential, commercial), function, and location on the University campus. According to the methodology proposed by O'Brien et al. [7], the team facilitator should have the task of delimiting attributions for each of the participants and defining the delivery deadlines, depending on the necessary feedback from each phase of the project. The technical drawings required by the contest announcement were: topographic survey; location and situation plan; architectural project; hydraulic installations design; electrical installations; air conditioning; lighting; and distributed generation project from renewable sources. Besides the Basic Project, there were other mandatory items to be delivered, such as Requirements of Use, Descriptive Memorandum, Budget, Schedule, Energy consumption, and distributed generation evaluation report and Preliminary Visitation Plan. It is noteworthy that the building must be open to visitation and monitored within 24months of its construction, to allow the measurement of its real performance.

The preliminary design of the building was done with a defined area due to budget constraints. Initial decisions and common goals must be developed with the participation of all.

According to the premises established in the methodology, the participants chosen were members of the research groups and laboratories at the University of Brasilia and those working closely with the NZEB theme and disciplines related, such as the postgraduate course Integrated Environmental Project, created in 2017 and taught in the Postgraduate Program in Architecture and Urbanism at the University of Brasília. This core team is coordinated by professors of the Architecture and Urban Planning -(Laboratory of Environmental Control and Energy Efficiency - LACAM), alongside with professors of Mechanical Engineering (Air-Conditioning Laboratory - LaAr) and Electrical (LARA - Automation and Laboratory) Robotics), partners since 2014 in the development of disciplines, undergraduate and graduate final works on the subject [20–22]. Professors of Geology and Environmental Science were also involved to develop themes related to the project's sustainability (water, waste, etc.).

The team was defined with 24 members, as follows: 2 architects specialized in energy efficiency, process coordinators; 2 specialists in a computer simulation, who transit between all other teams; 1 architect specialized in energy efficiency; 3 architects and 1 civil engineer without training in energy efficiency; 1 mechanical engineer specialized in energy efficiency (responsible for HVAC); 2 specialists in electrical engineers (1 responsible for photovoltaic energy generation, the other for controls and automation); 2 engineers specialized in budgeting; 2 engineers specialized in the use of water and waste; and 4 undergraduate students in Architecture. There was also the collaboration of a company residing in the University's Science and Technology Park, a specialist in energy efficiency labeling in buildings, and a junior company active in the field of civil construction, composed of graduate students in Civil Engineering and experts in the preparation of budgets for construction.

It was initially considered to use an NZEB residential building project, the result of an existing master's dissertation [22], but impasses regarding the use and occupation of a residential establishment on a university campus, in particular related to security and monitoring, eliminated this proposal. The second hypothesis dealt with the use of a retrofit project, carried out previously [15], in an existing building on the campus. In this case, the limiting factor was the cost, since it is a large building, the budget would exceed the amount offered by the Public Call. The Birck project [20], previously mentioned, due to its large area would also present a high cost. It was therefore decided to carry out a new building project on the campus.

After the initial discussions, the project's objective was defined as follows: to build an open and collaborative laboratory, which would allow for some flexibility in the plant without specific programmatic needs.

The city of Brasilia, where LabZERO|UnB will be constructed, is located in the central area of Brazil (latitude 15°46'South and longitude 47°55′ West) (**Figure 2**) and it has a climate that is classified as high-altitude tropical climate or Tropical savanna climate (*Aw*, according to the Köppen climate classification), milder due to the elevation (1.100 m). This climate is characterized by a rainy season, from October to April, and a dry season, from May to September. The average temperature is 21.0 C.

Initial design guidelines included local climate recommendations in bioclimatic zone 4 as per ABNT 15220 [23], which indicates shading, controlled natural ventilation, light and insulated roof, limited window-wall ratio, and light colors. Additionally, a floor plan with reduced depth was defined to favor natural lighting and it was installed with the largest façades facing North and South, to reduce the incidence of sunlight and optimize the protection of the façades. The roof houses the photovoltaic panels, as well as the North façade, which receives photovoltaic brises

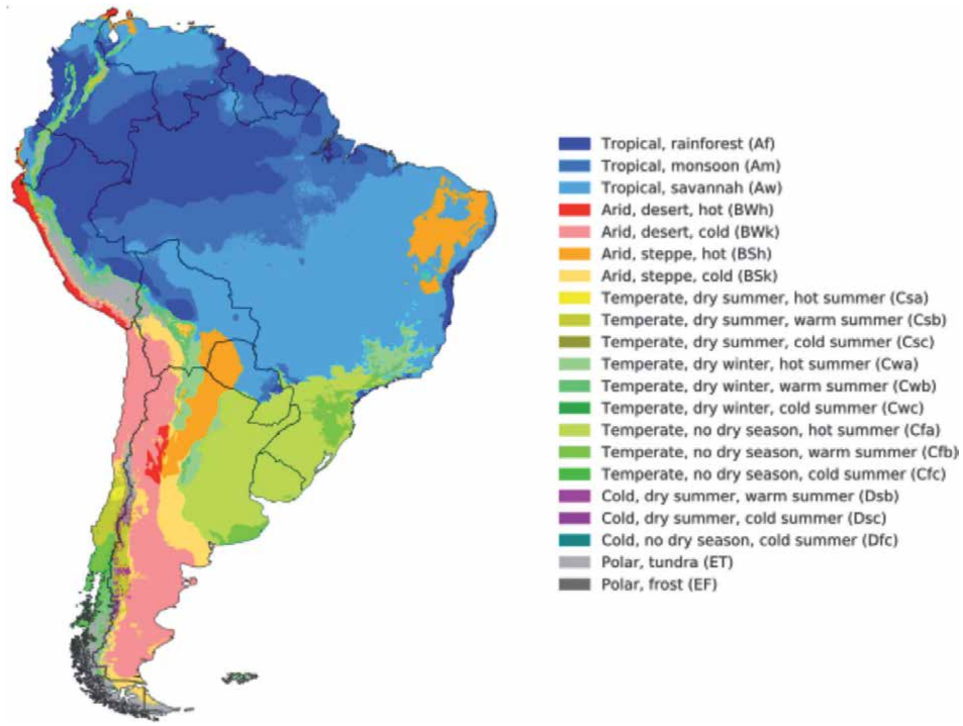

Figure 2.
Koppen-Geiger classification map for South America. Source: Beck, H.E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., berg, a.; wood, E. F.; present and future Köppen-Geiger climate classification maps at 1-km resolution nature scientific data. DOI:10.1038/sdata.2018.214., CC BY 4.0, https://commons.wikimedia.org/w/index.php?curid=74674070.

that also work as solar protection. The first design sketches (**Figure 3**) were developed based on these guidelines, but they gradually evolved as a result of discussions of the various aspects with the entire team. It is worth noting that the design process sought to harmonize esthetics with the local context of the university campus.

2.3 Simulations and preliminary draft

Computer simulations are carried out after the definition of the preliminary design to validate the first decisions regarding the implementation and orientation, the form of building, glazed area, solar protection systems, solar exposure for solar and photovoltaic panels. Some design variations and sensitive variables that feedback into the design process are tested in an integrated design action, in which team members participate. This process takes several weeks until an ideal energy solution is obtained.

To assess the building's energy performance, the Energyplus software was used through the DesignBuilder graphical interface for a period of a typical year. The results are presented by the energy consumption in kWh/m^2.year. The same software is used to perform the passive potential performance of the building's coworking area. In this case, the results are checked by the percentage of hours occupied in comfort using the adaptive comfort model of ASHRAE-55 for both 80% acceptability and 90%. As for the evaluation of the luminous performance of the coworking area, the Radiance program is used, through the Rhinoceros 3D program and its visual programming language Grasshopper and the add-on HoneyBee. The Daylight Autonomy (DA) is evaluated at 300 lux, and the Useful Daylight Illuminance (UDI) above 2000 lux.

The Basic Project, which is the level that the NZEB building proposal should be delivered for the PROCEL EDIFICA 2019 call notice [14], was defined after some alternatives were tested by simulation, in particular regarding sun protection, types of glass (light transmission and solar factor) and building materials (roofing and walls). In this phase, automation, and control strategies (HVAC and lighting), location of photovoltaic panels, such as Renewable Energy Technology (RET), lighting design, and other sustainability strategies, such as rational use of water and waste treatment, were also defined by teams of engineers and experts. The team participated in an integrated way. The group responsible for the simulations brought about results, which were evaluated under different aspects (energy, esthetic, functional, cost) before taking the final decision on the project.

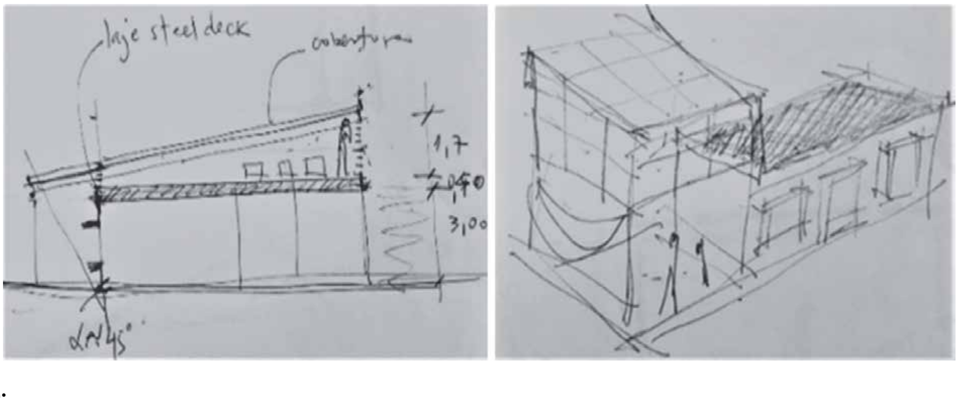

Figure 3.
Sketches with the first preliminary design risk, later revised (plan, volume, and section). Source: Authors.

Due to the first thermo-energetic simulations and daylighting, the preliminary design of the building was established.

After another round of simulations, the Basic Project was defined, bringing details of the preliminary project, such as envelope materials with thermal transmittance and absorptance suitable for the bioclimatic context (external walls, fiber cement panels, rock wool insulation, and plasterboard, U = 0.89 W/m^2.K; steel deck slab coverage, metallic tile, and insulation, U = 0.57 W/m^2.K); artificial lighting system with efficient lamps, luminaires, and task lighting; and automation for HVAC and artificial lighting.

2.4 Simulations and final calculations

After the definitions of the Basic Project, the feedback from the initial simulations, and the tests of several hypotheses, the final simulations of energy consumption involved the same software mentioned above. In addition to these, the RELUX software was used for simulations of the lighting project, the SAM software of the National Renewable Energy Laboratory (NREL) for dimensioning and calculation of two independent photovoltaic systems: on-grid and off-grid. Finally, energy efficiency labeling calculations, primary energy consumption, and budgets for final solutions, required by the notice, were performed. Regarding the budgets, a junior civil engineering company was counted on, which made the quotations of 21 items, plus the percentage of BDI, according to the model of the Public Call [14].

The simulations and final calculations prove that the building achieves an average annual consumption of electrical energy of 34.29 kWh/m2. year (7099.18 kWh/year), which corresponds to a primary energy consumption value of 54.88 kWh/m^2.year (11,358.68 kWh/year), that is significantly lower compared to the average consumption of electricity in office buildings in Brasília, which is around 130 kWh/m2.year [24]. As for the distributed generation of electricity in the photovoltaic system installed on the roof and side area, the value obtained is 58.29 kWh/m2.year. The results are consistent with international experiences in similar climates, presented above (**Table 2**). With these data, the achievement of the goal of building NZEB, or energy balance close to zero or nil, is proven.

The building's reduced energy consumption is achieved through architectural and technological strategies (passive and active). In addition to aspects of energy efficiency and comfort, the building proposes strategies for the rational use of water and waste management. Sustainability aspects are also highlighted, such as the steel structure and the sealings in prefabricated panels, allowing for quick and clean construction, with less waste generation and possible replicability of the typology.

The building obtained a level A energy efficiency label (the higher efficiency level, according to Brazilian National standards) as expected due to the inclusion of bioclimatic and energy efficiency strategies since its conception. In isolation, the envelope obtained EqNum = 5, the lighting obtained EqNum DPI = 5, and the air conditioning EqNumVent = 5, related to the Coefficient of Performance (COP) of the machines, with partial level A labels being obtained individually. As a bonus, it was counted the rational use of water (40% savings) and the energy savings from the network (more than 30%). The general prerequisite of dividing electrical circuits was also fulfilled. Therefore, the overall energy efficiency label obtained for the building is level A.

2.5 Design process: synthesis, limitations and potentialities

As indicated by the literature [3], the architecture started along with the conception of Renewable Energy Technologies (RET), which, in the present case, consisted of photovoltaic energy. Feedback cycles took place periodically between the thematic teams, together with the facilitators. The design of the building for the use of natural lighting also took place from the preliminary design. Soon after, the HVAC project, starting with passive strategies (ventilation, evaporative cooling, solar chimney) was initiated. The active HVAC strategies were designed right after the first thermo-energetic simulations, due to the hours of discomfort not passively resolved, giving rise to the preliminary project. At this point, an initial calculation of the building's energy balance was carried out (with data from the first thermo-energetic simulations and the photovoltaic panels still only on the roof). Then the sunshades and openings were readjusted to correct some identified problems. As a result of natural lighting simulations, with the building being better defined, the lighting, electrical, controls, and automation projects were carried out. In this preliminary project phase, strategies were also conceived for the rational use of water (hydro-sanitary project) and waste treatment, which are complementary aspects of the project's sustainability. The final thermo-energetic simulations, labeling, primary energy calculations, and final energy balance of the building were carried out after the definition of the envelope materials, the internal finishes, and the basic project, **Figure 4** presents the design process, products, and flows, relating them to the iterative phases mentioned in **Figure 1**.

The process took place relatively smoothly, due to the aforementioned previous tests, involving part of the team. However, some important points that emerged from the experience with time and budget limitations should be mentioned: 1. The role of the facilitators is essential to coordinate the various decisions to be taken that

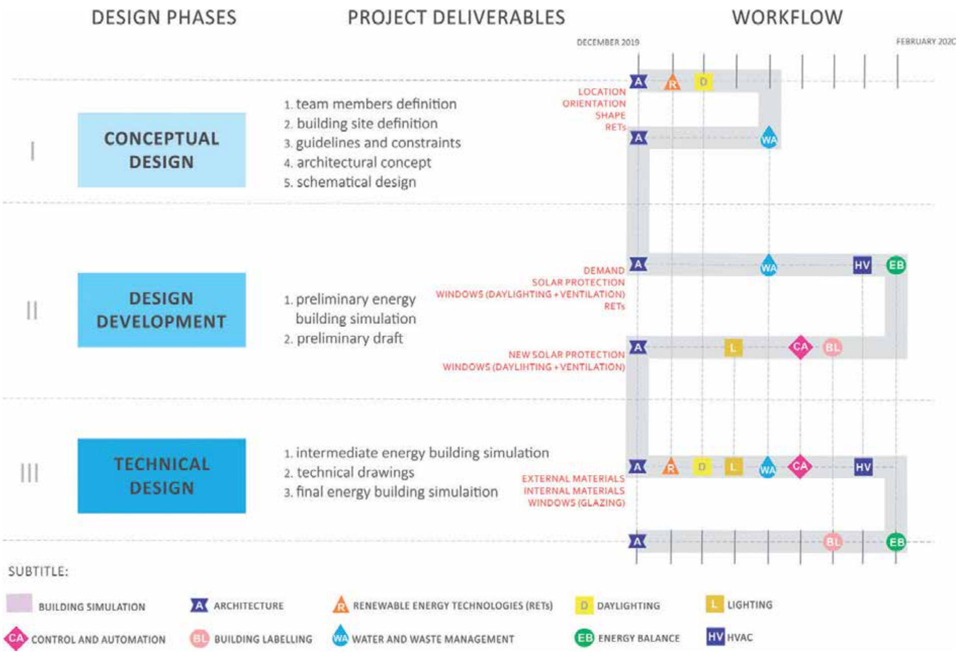

Figure 4.
Design process, with products and design flow. Source: authors.

require inputs and results from different thematic teams; good facilitators are crucial for meeting deadlines and are potential drivers of positive results; 2. Efficient communication with the various thematic teams is included in the role of the facilitators, to delimit the level of detail of the solutions proposed by each one, in each phase. In the early design phases, the level of detail should be lower, to avoid wasting time and rework; in the final stages, the level of detail is higher. There seems to be a tendency among specialists to get the phases in detail from the beginning., to be controlled by the facilitators, as it represents a barrier to the fluid development of the process; 3. The simulation team also has a fundamental role and interacts with other teams, as they need to "translate" the architectural proposals into simulation results, which feedback the new architectural proposals. For this, communication must be effective, and the language adapted to reach all professional profiles, which is not simple and can become a barrier in the process; 4. Periodic meetings, sharing information, and decisions are important for team involvement and motivation. However, in some moments, quick decisions must be taken and for this, again, the role of the facilitators is fundamental.

3. The LabZero UnB project: Design, performance analysis and energy balance

This section presents the final design of LabZERO|UnB building, as a result of the previously described design process. The performance analysis, computational simulation process, and final energy balance are also presented.

3.1 The final design of LabZERO|UnB

The LabZERO|UnB construction is predicted to be done at the Science and Technology Park, at the Darcy Ribeiro campus of the University of Brasília (UnB), which aims at socio-economic development and strengthening research, development, and innovation (RD&I) structures. The privileged location on the campus provides the building with excellent visibility and easy access for the visitors (**Figure 5**).

Once built, the LabZERO|UnB building will be used for office activities in a coworking regime, to house research groups of UnB's Architecture and Engineering Faculties dedicated to the study of zero energy balance and sustainability in buildings, (**Figure 6**).

In terms of architectural design, the basic assumption was the adequacy of the architecture to favor the use of passive resources, respecting the local climate recommended strategies for bioclimatic zone 4 (Bioclimatic Zone 4, [23]), which includes shading, controlled natural ventilation, roof insulation, among others, as mentioned before in 2.2.

It was also a premise that architectural style was in accordance with the construction standards of the University of Brasília, highlighting, in the volumetry, some of the innovative systems used in the building.

Considering the educational and representative character of LabZERO|UnB, both internally and externally, the architecture uses innovative systems as elements of a visual framework, to highlight the applied design decisions, such as the steel structure, apparent electrical installations, and visual integration between the technical area and the work environment. As for the building's morphology (**Figure 7**), the elongated and shallow shape, with larger façades towards the North–South orientation, allows the use

Figure 5.
Location of UnB campus Darcy Ribeiro in Brasilia.

Figure 6.
Building plot on the Darcy Ribeiro campus (left) and implementation (right). Source: [25].

of natural light and optimized and effective sun protection [25]. The glazed area on the façades is limited to 35% and duly protected from excessive sun radiation using louvers. On the North façade, they are indeed a BIPV (building-integrated solar photovoltaics) solar louvers, whilst a solar chimney system is present on the West façade to intensify natural ventilation, combined with forced ventilation when necessary (**Figure 7**).

The floor plan has 207 m^2, arranged as an office area (with an area reserved for meetings), a pantry, a bathroom, a dressing room, a technical area, and a bicycle rack, in addition to an outdoor balcony. **Figure 8** shows the layout of the building plan.

The constructive systems elected to be used in this project are envisaged to strengthen sustainability and technological innovation. In addition, institutional criteria had to be met regarding the possibility of reproducibility, relocation, and integration with industrialized dry-construction systems, which reduce losses and

Figure 7.
3D perspective view of LabZERO|UnB building from northeast [25].

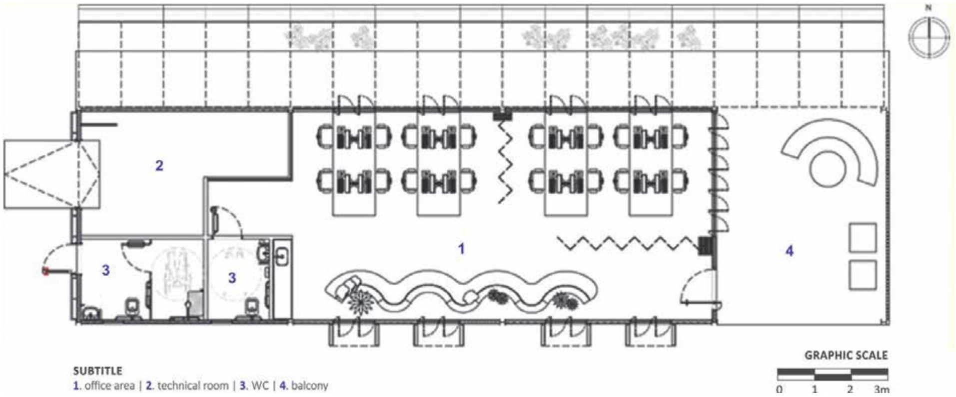

Figure 8.
Floor plan of LabZERO|UnB building. Source: [25].

waste in construction, ensuring faster execution. The building envelope systems are composed of a composite steel deck slab plus 12 cm of concrete employed on the floor and the roofs, whereas external walls are constituted by external fiber cement panel and drywall internally, filled with 4 cm of rock wool for insulation. Internally, all partitions are composed of two drywall panels with an air cavity, except for the partition between the office area and the technical area, which employs a clear 6 mm glass.

As complementary processes, in addition to natural lighting and ventilation, it was included an induced (or forced) ventilation system using a solar chimney. When comfort conditions with natural ventilation and induction were not sufficient, a set of high-efficiency exhaust fans with speed control is activated, maintaining the necessary airflow for the occupied space. Additionally, to the several passive systems and techniques envisaged to maintain thermal and lightning comfort conditions, the building's energy efficiency is guaranteed by highly efficient artificial lighting and HVAC appliances. The project will have a rational use of drinking water, besides the use of alternative water sources, distributed generation with grid-connected photovoltaic generators, waste management, accessibility, and new technologies (**Figure 9**).

From the early stages, the building was conceived to achieve high performance and renewable energy generation instead of contemplating only conservation, efficiency, and energy generation measures in the final stages of the project. This is especially relevant because it is in the initial design stage that there is the opportunity to reduce the project costs and avoid future rework [26]. However, in order for this to happen, the project methodology contemplated interaction and collaboration between the various agents and disciplines that interfere in the project development, which in fact occurred in the experience of LabZero at the University of Brasília (LabZERO|UnB).

3.2 Performance analysis guidelines

Several aspects of the project were evaluated using computer simulation tools, not only to estimate electricity consumption, generation demands, and comfort conditions, essential for the development of a zero-energy balance building project but also to support the decision-makers in design. The computer simulation tools also helped to envision the building's tagging process. In this section, the main guidelines and assumptions for environmental and energy performance analysis of the LabZERO|UnB project are presented.

3.2.1 Daylighting

For daylighting analysis, the Radiance program was used through the Daysim/Honeybee graphic interface, and Grasshopper/Rhinocerous3D plugin (**Figure 10**). To evaluate the performance of daylighting, 2 metrics were used: DA (Daylight Autonomy – or Natural Lighting Autonomy) considering 300 lux, and UDI (Useful Daylight Illuminance) considering a maximum of 2000 lux. In both cases, the measurement plane considers the height of the work plane at 80 cm in relation to the floor and the mesh of stitches distributed every 50 cm. In terms of the availability of natural light during the period of occupation of the building, the interval from 8 am to 6 pm was considered valid, during all 12 months of the year.

3.2.2 Lighting

Artificial lighting was designed considering daylighting availability. The computer simulations used to verify the condition of artificial lighting in the building were

Figure 9.
On the left, the perspective shows the BIPV solar louvers on the north façade and a solar chimney on the west façade; on the right, the perspective of the south façade source: [25].

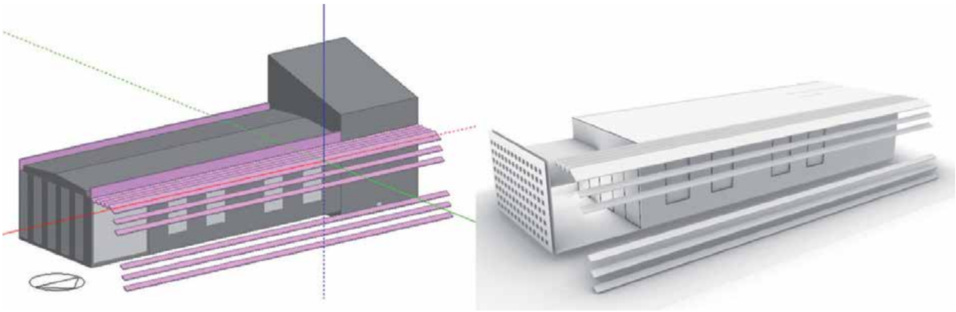

Figure 10.
On the left, modeling in DesignBuilder and on the right modeling in rhinoceros 3D [25].

carried out by modeling and calculating the data through the/Relux software, version 2019.3. The objective was to optimize the energy efficiency of the system, ensure adequate lighting rates, according to [27], and serve as a basis for an energy assessment. The input data were: the building geometry (height, width, depth, and useful ceiling height); the artificial lighting equipment in each environment; and the height of the work plane (70 cm).

3.2.3 Thermo-energetic performance

To analyze the building energy performance and to verify the electricity demand, EnergyPlus 8.9 was used, through the graphic interface DesignBuilder 6.0 (**Figure 10**). The model's geometry followed the architectural design, and the climate file was a Swera type for the city of Brasília-DF.

The loads and schedules utilized are based on the ASHRAE Handbook of Fundamentals [28] mostly for generic office area, which is the predominant occupation. The office breakroom in the outside area and bathrooms follow also the same indications [25], however, they are adapted to the Brazilian reality, so no plug load is considered in these areas. Additionally, since the technical area does not have heavy machinery, instead of the 52 W/m^2 considered to this kind of area in the ASHRAE Handbook of Fundamentals (2017), it is employed the same value of generic office area, of 11 W/m^2, which allows a general load closer to the generic offices found in Brasilia by Costa et al. (2018). The attic is considered unoccupied with no internal loads. Furthermore, the artificial lighting energy values are obtained from the lighting design, with an overall 5 W/m^2 for all environments, meanwhile, in the office area, there is an additional 1 W/m^2 for task lighting. **Table 3** summarize these data:

Additionally, the building operation varies from 8 h to 22 h on weekdays and all schedules are derived from this operation period. The simulation is carried out for the whole year and the data analyzed is Energy Use Intensity (EUI) in kWh.year/m^2, considering only the occupied area (not including the attic).

The reflectance of materials is based on the general guidelines of [12], which defines absorbance values for light colors as 0.4 and for dark colors as 0.7. The floor and the ceiling were modeled as dark, while other surfaces were defined as light.

The building envelope thermal properties follow the standards of [23], with [29] reference for modeling in EnergyPlus. The external vertical sealing composition comes from [22], external walls of fiber cement and rock wool (0.89 W/m^{2}K), in addition to a covering composed of metallic tile with insulation (0.80 W/m^{2}K), ventilated cavity

Item	Office	Breakroom	Water closet	Technical area	Attic
Occupation (person/m^2)	0,1100	0,2889	0,1124	0,1110	—
Equipment (W/m^2)	11,77	—	—	11,00	—
Artificial lighting (W/m^2)	5 + 1	5	5	5	—

Table 3.
Occupation, equipment, and lighting power per area type.

(10 ren/h), and steel deck slab (3.16 W/m^{2}K). The thermal properties of all layers of the opaque envelope are presented in **Table 4**.

The glass employed on the windows is a clear laminate 13 mm glass (6 mm+1 mm PVB+6 mm) (**Table 5**). All windows have external shading elements, as recommended for this climate.

As for electrical equipment, the installed power follows the RTQ-C as a reference [11], except for lighting that respects the project presented in the analysis of the artificial lighting system. The usage routine is from 8 am to 10 pm 5 days a week. With the exception of the coworking area, the other areas have natural ventilation. Bathrooms, technical area, and balcony have the ventilation network model (airflow network). According to the project, the frames opening rate is 88%.

For the attic zone, a constant rate of 10 renewals per hour is used. The office working area will be equipped with a highly efficient direct expansion HVAC system for cooling purposes. No heating will be employed since it is most frequently necessary late at night when there is no occupation in the building. It is employed ideal air loads for the mechanical systems with a Coefficient of Performance (CoP) of 5, which is a theoretical constant value for the equipment employed. There is also a cooling

Systems	Layers	Width (cm)	Conductivity (W/m.K)	Specific Heat Capacity(J/kg.K)	Density (kg/m^3)	U-Value (W/m^{2}K)
Steel Deck Slab	Steel	0,6	55,000	460	7800	3,16
	Concrete	12,0	1130	1000	2000	
Double Metal Roofing with Insulation	Steel	0,6	55,000	460	7800	0,47
	Rock Wool	9,0	0,045	800	100	
	Steel	0,6	55,000	460	7800	
External Wall	Fiber Cement Siding	1,0	0,950	840	550	0,89
	Rock Wool	4,0	0,045	800	100	
	Drywall	2,0	0,350	870	900	
Internal Partition	Drywall	2,0	0,350	870	900	1,80
	Air Cavity	11,0	Fixed R-Value of 0,18 m^2.K/W			
	Drywall	2,0	0,350	870	900	

Table 4.
Opaque envelope thermal characterization.

Characteristics	Clear glass 6 mm
SHGC (W/W)	0.74
Light transmission (W/W)	0.86
U-value (W/m^{2}K)	5.29

Table 5.
Glass thermal properties.

setpoint of 24 °C operative temperature with no setbacks. Finally, a water condensing unit is used in combination with an evaporator fan, which blows cold air from a plenum under the floor of the working area.

In addition, there is artificial lighting control in this zone, with setpoints of 150 lux for the balcony area and 300 lux for the coworking area.

3.2.4 Potential for photovoltaic energy generation from on-grid and off-grid systems

To analyze the potential of photovoltaic energy generation, the SAM software from the National Renewable Energy Laboratory (NREL) was used. Two different photovoltaic systems were designed. The first one was a photovoltaic field of a kind that is connected to the public distribution network (on-grid), integrated to the coverage of the technical area of the building, facing North, with an inclination of 15°. The other photovoltaic system was conceived as an integrated field to the design of the brise-soleil that shade the North façade – using a battery bank for storage (off-grid), and will not be directly connected to the public grid. This unusual design is intended to address future research regarding demand energy management.

A system with 12 TRINASOLAR TSM-DE15MII-400 W TALLMAX modules of 400 Wp of monocrystalline silicon was considered for the on-grid system and YINGLI YL100P-17B 2/3 panels 36,100 W POLYCRYSTALLINE CELLS with measures 2.5x66x101cm and 100 W of power in the standard STC test conditions for the off-grid system. For the calculation, the methodology of Pinho and Galdino [30] was used.

3.3 Daylighting analysis

The daylighting simulation reveals the availability of this resource in the coworking area, as shown in the Daylight Autonomy map (**Figure 11**). There is a predominance of natural light autonomy in the environment for over 80% of the hours during the year, with more than 300 lux. Illuminance values above 2000 lux, which can lead to glare and excessive thermal loads, are punctual and appear less than 40% of the time. In addition, they are concentrated exclusively along the building openings, as shown in **Figure 11**.

In general, and in terms of the high daylight availability when the environments are occupied, the results are satisfactory. Values with an autonomy of 300 lux less than 80% of the time are punctual (behind the wall and in rooms such as pantry and hallway, which usually do not have high lighting demand). Likewise, the compensation to reach higher levels, such as 500 lux in the work planes, can be contemplated by the work luminaires foreseen in the lighting project (task lighting). Furthermore, it is noteworthy that it would be highly restrictive to demand that the entire environment be served by 500 lux. In terms of potential glare, the 2000 lux Useful Daylight Illuminance analysis indicates dew occurrences near the windows, which can eventually be avoided

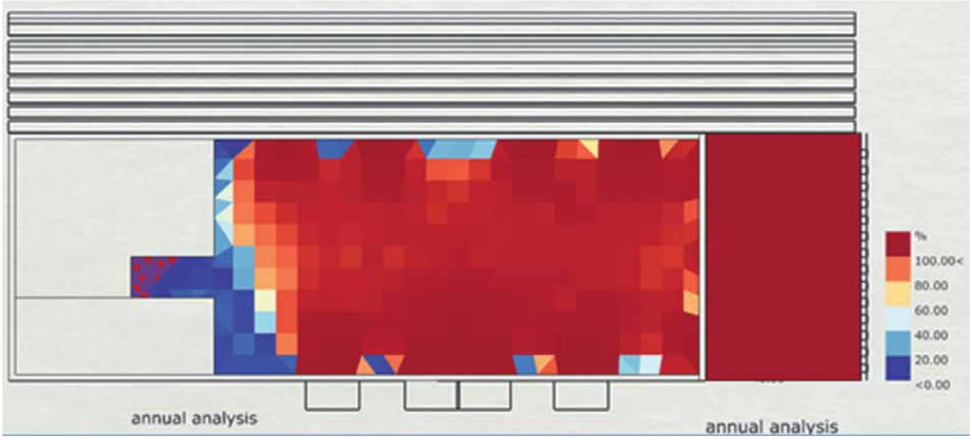

Figure 11.
300 lux daylight autonomy (DA) map for the Coworking and balcony area [25].

by adopting simple solar protection systems, such as blinds. In the external area and balcony, there are naturally higher rates, especially at the end of the building, which would probably benefit from some kind of greater protection (**Figure 12**).

3.4 Analysis of the lighting system

The adoption of high-efficiency solutions enabled an average illuminance of 411 lux in the coworking environment, as indicated by the simulations in Relux. At the workstations, the use of task luminaires that increase the illuminance to 500 lux on average is foreseen, as required by the NBR ISO/CIE 8995-1:2013 standard [31].

Thus, the project predicts a total of 54 luminaires, considering all areas and environments, with a total power of 801 W and a lighting power density (LPD) of 3.87 W/m^2. The minimum illuminance level required by NBR ISO/CIE 8995-1:2013 [31], entails an increase of 1 W/m^2, which raises the DPI to 4.87 W/m^2. Even so, this

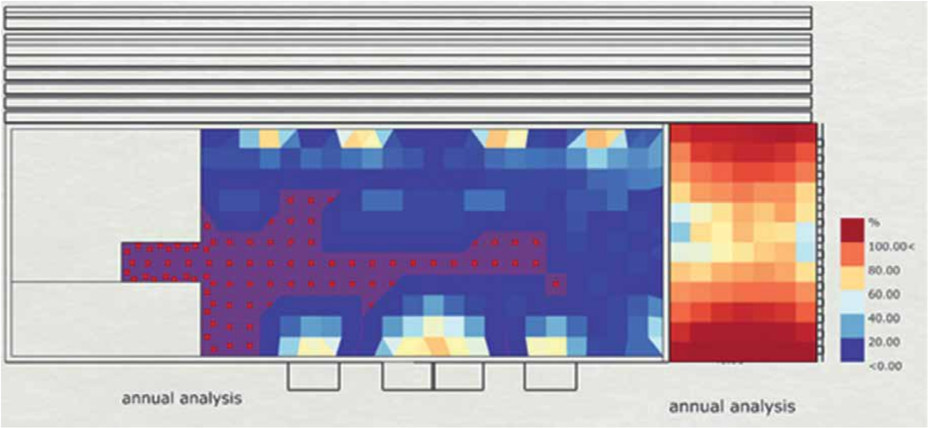

Figure 12.
Useful daylight Illuminance (UDI) map above 2000 lux for the Coworking and balcony area [25].

performance is considerably higher than the limit estimated by label A, according to the PBE Edifica PROCEL classification [11]. This demonstrates, in part, the potential for reducing LPD by using high-efficiency equipment.

This low LPD, combined with the control and automation system with sensors and dimming of the integration system between day and artificial lighting, allows a significant reduction in energy consumption. These elements are considered and verified later in the evaluation through simulation of energy performance.

3.5 Energy performance analysis

The building's energy consumption results assume a conservative scenario, with artificial conditioning of the coworking area throughout its occupation. However, the main objective of the project proposal foresees that conditioning should be applied only in situations when thermal comfort is not provided. Especially due to the great potential of using passive strategies. Nevertheless, it is prudent to take a conservative stance to ensure that the project will reach its goal of a building with a zero-energy balance.

Given the potential of taking advantage of natural light, the low demand for artificial lighting, the high-performance envelope, and efficient air conditioning equipment, it is possible to obtain an energy consumption of 34.30 kWh/m^2.year, as shown in **Table 6**. As a comparison criterion, the value obtained is considerably lower than the standards for corporate environments in Brasília-DF listed by [27], which demonstrates an average consumption of 131 kWh/m^2.year.

Thus, the division of consumption by final use, as shown in **Figure 13**, is considerably different from the typical consumption for commercial buildings foreseen by [32]. Unlike almost half (47%) of the energy consumption being related to the conditioning system, at LabZERO|UnB the conditioning system corresponds to 39%. It is worth noting that this reduction could be even more significant if a less conservative scenario were used regarding the air conditioning adoption. However, a greater reduction, from 22–12%, is seen in the artificial lighting system.

As for other electrical loads (equipment), demand exceeds the 31% predicted by [32], reaching 49% at LabZERO|UnB. This percentage does not reflect a quantitative increase in this type of load. However, it shows that its participation in the energy matrix of the building is greater. In part, this is justified by the fact that air conditioning and lighting systems are the main focus of these studies, being directly linked to architecture. For the calculation of energy demand of other electrical equipment, the standard was kept as a default. According to the very concept of building efficiency, the equipment adopted will probably follow the high-efficiency standards, which

End uses	**Annual electrical energy consumption (KWH/year)**	**Annual electrical energy consumption (KWH/m^2. year)**	**Percentage (%)**
Office Equipment	3451,13	16,67	49
Lighting	874,20	4,22	12
HVAC	2773,95	13,40	39
Total	7099,28	34,30	100

Table 6.
Consumption data by final and total uses per year and per year per square meter for the entire building [25].

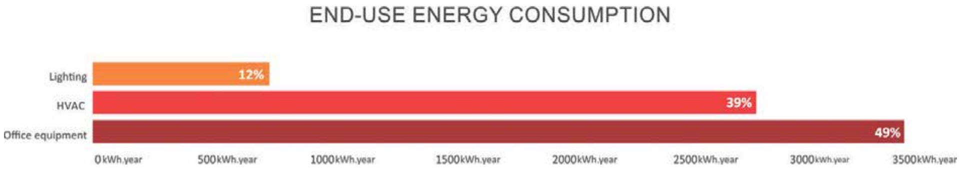

Figure 13.
Energy consumption by end-use [25].

reduces its demand. However, as the proposal aims to seek a more conservative scenario, this reduction was not considered for these environmental and energy performance analyses in the design stage.

3.6 Analysis of the potential for generation of photovoltaic energy

The graph in **Figure 14** shows the results of potential photovoltaic energy generation for the 2 systems (on-grid and off-grid), while **Table 7** presents the total values. It is observed that the on-grid system placed on the roof has significantly higher generation than the off-grid system, located in the brises, of 7,933 kWh/year and 4,155 kWh/year, respectively, which totals 12,088 kWh/year.

3.7 Building energy labeling

The building obtained a level A of energy efficiency label (the higher efficiency level, according to Brazilian National standard), as expected due to the inclusion of bioclimatic and energy efficiency strategies since its conception. Individually, the building envelope obtained EqNum = 5, the lighting system obtained EqNum DPI = 5, and the air conditioning system obtained EqNumVent = 5, related to the Coefficient of Performance (COP) of the machines. Considering a partial level A labeling

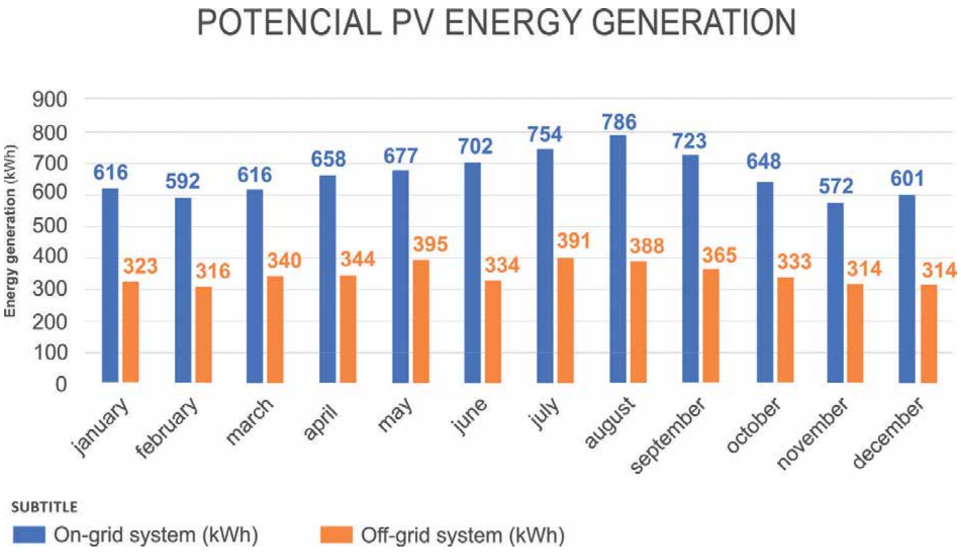

Figure 14.
Monthly estimated PV solar energy generation for LabZERO/UnB [25].

	On-grid (kWh)	Off-grid (kWh)	Total (kWh)
Power generation	7933.02	4155.18	12,088.2

Table 7.
Total values of photovoltaic energy generation potential in on-grid and off-grid systems.

obtained individually by these systems, plus a bonus for the rational use of water (40% savings), the energy savings from the network (more than 30%), and the general prerequisite of dividing electrical circuits fulfilled, the overall energy efficiency label obtained for the building is A, the most efficient.

3.8 Energy balance analysis

The graph in **Figure 15** shows the energy balance between consumption and generation. Even when considering the most conservative consumption, with the use of the conditioning system during the entire period of occupation, the simulations and final calculations prove that the building achieves an average annual electrical energy consumption of 34,29 kWh/m^2.year (7,099.18 kWh/year), which corresponds to a primary energy consumption value of 54,88 kWh/m^2.year (11,358.68 kWh/year). This is a significantly lower number if compared to the average consumption of electricity in office buildings in Brasília, which is close to 130 kWh/m^2.year [24]. As for the distributed generation of electricity in the photovoltaic system, installed on the roof and side area, the value of 58,29 kWh/m^2.year is obtained. The results are consistent with international experiences in similar climates, presented before (**Table 2**). With these data, the achievement of the building NZEB goals, or energy balance close to zero or nil, is achieved. There is, therefore, full compliance with the condition of the NZEB building (almost zero energy balance). It is also proposed that the energy generated in excess should be used to supply electric bikes and other buildings at the University of Brasília campus.

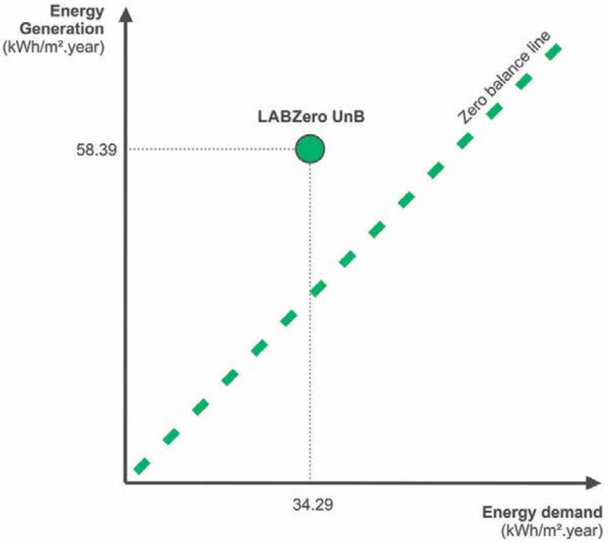

Figure 15.
Graph of the energy balance between building consumption and generation [25].

The building's reduced energy consumption is achieved through architectural and technological strategies (passive and active). In addition to aspects of energy efficiency and comfort, the building project proposes strategies for the rational use of water and waste management. Sustainability aspects are also highlighted. An example is the steel structure and the sealing in prefabricated panels, which allow for quick and clean construction, reducing waste generation and the replicability of the typology.

4. Conclusions and perspectives

The integrated design process, used as a methodology, proved to be efficient and highlighted the possibility of transposing research experiences into design practice. The barriers and potentialities related to the coordination of a multidisciplinary team and the organization, planning, and achievement of the goals in the integrated project process stand out. It is important to highlight the role of the computer simulation and the team in charge of this item in the design process, which must interact with others and effectively communicate the results. The project also underlines the importance of the facilitators, who coordinate the feedback loops of the computer simulations and architectural, the technological decisions between specialized teams and the group as a whole, in addition to defining deadlines and levels of detail for each specialty. Communication problems in the team can constitute barriers in the process, and the tendency of excessive detailing by experts at the beginning of the design process must be monitored by the facilitators.

The tools for analyzing environmental and energy performances through computer simulations are key parts to verify the zero-energy balance of a building and the fundamental elements in design decision-making. With these tools, the performance results can be accurately estimated.

In addition to being a building with a zero-energy balance, LabZERO|UnB is a project with the capability to achieve a positive energy balance, by offering an annual generation higher than its consumption. It has a demand of 34,29 kWh/m^2. year and a generation of 54, 88 kWh/m^2. year, which represents the potential to become a construction that has a positive energy balance with a 60% margin. This result occurs even considering conservative hypotheses of consumption reduction – such as constant use of artificial conditioning, with passive potential and office equipment with regular efficiency. Thus, the reduction in the energy consumption pattern from 131 kWh/m^2. year to 34 kWh/m^2. year is mainly due to solutions linked to the characteristics of the architectural project, such as shape, envelope, quantity, and opening orientation, combined with high-performance, artificial lighting, and mechanical conditioning systems. These indicate the advantage of considering environmental performance demands from the early stages of the project to achieve high-performance buildings.

It is expected that the construction of LabZERO|UnB, as well as the ELETROBRAS/PROCEL competition initiative, will be a milestone in the development of high-energy performance buildings in Brazil and zero-energy balance constructions. However, there is a need to incorporate environmental and energy performances analysis tools in the scope of the architectural project development from the preliminary stages, keeping in mind the operation and monitoring phases.

As a result, the project achieved an energy consumption of almost four times lower than the local average for office buildings, and this is compatible with international experiences. As the energy generation exceeds the demand, the NZEB building has the potential to supply other constructions or equipment. The strategies used for this combine the architecture plan conceived according to the local climate and directed towards the energy production in the building itself; and the main adoption of passive strategies, with the use of controlled active methods to optimize energy expenditure. After its construction, the building may be open to the public with a demonstrative purpose, allowing for large-scale dissemination.

Creating LabZERO|UnB reinforces the necessity of developing more sustainable and resilient buildings, with a possibility to extend the adopted strategies to other similar constructions creating, therefore, more efficient cities. This building will be a great model on the University campus, and it can be a prototype for future structures. It also works as a laboratory, in which people can better understand the importance of bioclimatic design and the incorporation of energy production on the building. Some architectural premises that were used on this project could also be applied in other constructions in the Brazilian context. Ultimately, LabZERO gives data to the Brazilian government to support public policies related to energy efficiency and sustainable energy production, all objectives which are bonded to the UN Sustainable Development Goals (SDG). In the context of the climate crisis, energy efficiency must be the natural strategy for developing countries in a tropical climate zone.

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