UNIVERSIDAD NACIONAL AUTÓNOMA DE MÉXICO
PROGRAMA DE MAESTRÍA EN INGENIERÍA
INSTITUTO DE ENERGÍAS RENOVABLES
ENERGÍA – DISEÑO BIOCLIMÁTICO

EVALUATION OF THE NZEB DEFINITIONS IN A NEW BUILDING AT IER-UNAM

TESIS
QUE PARA OPTAR POR EL GRADO DE:
MAESTRO EN INGENIERÍA

PRESENTA:
ING. JOSÉ IGNACIO MACIEL HERNÁNDEZ

TUTOR PRINCIPAL:
DR. GUILLERMO BARRIOS DEL VALLE – IER UNAM

COMITÉ TUTOR:
DR. JORGE ANTONIO ROJAS MENÉNDEZ – IER UNAM
DR. JOSÉ MANUEL OCHOA DE LA TORRE – UNISON
DRA. AIZAILADEMA ALTAMIRANO ÁVILA – CFE
M.I. ANA GABRIELA ÁLVAREZ ALMEIDA – dbHMS

TEMIXCO, MORELOS, MAYO DEL 2024

Agradecimientos

Al Instituto de Energías Renovables (IER), por haberme brindado por varios años una segunda casa en la que siempre me sentí muy cómodo. Las mejores experiencias que he tenido hasta la fecha fueron dentro de sus paredes.

A la Universidad Nacional Autónoma de México (UNAM), por abrirme las puertas a un mundo totalmente nuevo y ayudarme a crecer como persona. Todas las experiencias y apoyos que recibí hicieron que mi perspectiva de la vida cambiara y aprendiera que del esfuerzo siempre se puede ganar algo. Desde pequeño siempre quise estudiar aquí y también le voy al equipo de fútbol, entonces espero ver próximamente la octava.

Al Consejo Nacional de Ciencia y Tecnología (CONACYT), por haberme dado la beca que permitió que pudiera concentrarme totalmente en la elaboración de este trabajo.

A mi tutor, el Dr. Guillermo "Memo" Barrios, quien me acompañó y guió en este arduo proceso. Definitivamente ninguna de las siguientes páginas hubieran sido posibles sin tu ayuda. No hay palabras para expresar lo agradecido que estoy contigo por todo lo que me has enseñado y por haber sido tan buen tutor, maestro y amigo. Una gran parte de este triunfo también es para ti. A mi comité de tutores, Dr. Jorge Rojas, Dr. Manuel Ochoa, Dra. Aizailadema Altamirano y M.I. Gabriela Álvarez, por ayudarme a mejorar mi trabajo y enriquecerlo con su experiencia.

A mis amigos de Acapulco, por siempre estar ahí desde que éramos niños, por todas las reuniones nocturnas épicas, por todas las anécdotas divertidas que hemos creado con el tiempo, y por que, aunque a veces nos llevemos algo pesado, estoy seguro de que estarán ahí cuando los necesite y en los momentos más importantes de mi vida.

A mis amigos y profesores del IER, por hacer que mis días en el Instituto fueran los más divertidos e interesantes. De cada uno de ustedes me llevo una buena anécdota o una valiosa lección. A mi querida 7G, por ser la razón principal de que Temixco fuera tan genial. Disfruté mucho todos los momentos dentro y fuera de la clase. A cada uno de ustedes los llevo en un lugar muy especial de mi corazón. Por último, a mi estimado colega Daniel Ramírez, por ser la primera persona en darme su apoyo y creer en mí cuando más lo necesitaba.

A mi familia, por siempre tener las palabras que necesito para seguir avanzando y por darme una infancia llena de cariño y risas. A mis abuelos Francisco, Ignacia y Sully, por ser mis segundos padres y cuidarme toda la vida, por platicarme mil historias que siguen maravillándome hasta la fecha y por enseñarme a ser una persona agradecida y bondadosa con la gente. Abuelito, este triunfo va para ti, siempre portaré con orgullo el apellido que nos diste. A mi hermano Sebastián, por enseñarme que, aunque mi mundo se esté cayendo a pedazos, siempre tendré un lugar a donde ir. A mi hermana Sully, por siempre estar detrás de mí para ver qué no me haga falta nada. A mi padre Francisco, por siempre ser el héroe que me salva cuando las cosas se ponen difíciles. Y por último, a mi madre Martha, por enseñarme todas las lecciones de vida que me han permitido llegar aquí, por enseñarme que las metas y los sueños se cumplen si trabajas por ellos con esfuerzo y por siempre creer en mí aunque me la viva en la cuerda floja.

A mi mismo, por nunca haberte rendido a pesar de las adversidades. Aunque al principio algo te parezca imposible, siempre confía en que puedes lograrlo y esfuerzate mucho para conseguirlo. Felicidades por este triunfo. ¡Sigue así!

Abstract

This thesis, embarked upon at the Renewable Energy Institute (IER for its acronym in Spanish), delves into the potential of Net Zero Energy Buildings (NZEB) as a cornerstone of sustainable architectural practice in Mexico, aligning with the urgent global and national imperatives for climate action. The building sector's significant contribution to global energy consumption and greenhouse gas emissions calls for transformative solutions, which this study addresses through the exploration of NZEB definitions and their applicability within the Mexican context.

In the first part of the thesis, the introduction sets the stage by defining the scope and significance of NZEBs. It discusses the environmental, economic, and social drivers behind the shift towards energy-efficient buildings globally, and particularly in Mexico. This section lays the foundational understanding of the energy challenges buildings pose and introduces the conceptual framework of NZEBs that aims to balance energy consumption with renewable energy generation.

The literature review in the subsequent section offers a detailed examination of NZEB research at international, national, and local levels. This comprehensive review not only highlights the pioneering studies and projects around the world but also pinpoints the gaps in research concerning Mexican non-residential buildings. It underscores the need for localized research to adapt global insights to Mexico's unique climatic, technological, and regulatory contexts.

Focusing on the practical application of these concepts, the study presents a case analysis of a new building at the IER. This case study critically assesses the building's design and operational features against the four NZEB definitions and to evaluate them, it is crucial to collect specific data such as building energy consumption and renewable energy generation. These data are common elements in all NZEB definitions. To obtain them, a numerical model of the new IER building was built in EnergyPlus. Building this model required collecting data on miscellaneous equipment, lighting, and LP gas consumption. Once the model is completed, both annual energy consumption and annual renewable energy generation can be calculated, which are essential data for evaluating all NZEB definitions. The findings of this empirical investigation reveal that the new IER building could achieve three of the four NZEB definitions if it implements the two renewable energy options planned for the project.

The discussion section synthesizes the insights from the theoretical and empirical analyses, reflecting on the challenges of implementing NZEB standards in Mexico. It evaluates the barriers to adoption, such as cost implications, technological limitations, and policy constraints, and suggests strategies to overcome these hurdles. The study emphasizes the importance of an integrated approach that combines policy innovation, technological advancements, and economic incentives to foster the broader adoption of NZEBs.

The thesis concludes with a forward-looking perspective, proposing pathways for future research and policy-making. It advocates for a multi-disciplinary approach to developing more robust frameworks for NZEB implementation, suggesting that further studies should explore the scalability of NZEB solutions across different regions and building types to ensure wide applicability and effectiveness.

In essence, this thesis provides a critical and comprehensive exploration of NZEBs within the Mexican context, offering valuable insights and practical recommendations for stakeholders aiming to advance the sustainability of the built environment. Through this scholarly endeavor, the study contributes to the global discourse on sustainable development and lays down a blueprint for future actions in the realm of energy-efficient building practices.

Contents

List of Figures

Chapter 1

Introduction

1.1 Energy, emissions and buildings

According with Klepeis et al. [2001] and World Health Organization [2014], most of people worldwide will spend 90% of their life in indoor spaces, also known as buildings. That is the main reason why building construction sector and operation of buildings is responsible for 34% of the global final energy consumption and 27% of global emission related with energy sector [IEA, 2023]. In Mexico, the operation of buildings account for 20% of the final energy consumption [SENER, 2023] and 15% of emissions related with energy sector [SEMARNAT, 2021]. Energy consumption and CO2 emissions generated by buildings will continue to increase until building owners implement an efficient way to design and operate their constructions. Since long time ago, several organizations around the world have realized that they can fight a part of climatic change, reduce global energy consumption and reduce the carbon footprint of human activities by changing the way we make and use buildings.

The monitoring of the United Nations Sustainable Development Goals (SDGs) is closely related to the current imperative of designing and constructing Net Zero Energy Buildings (NZEB) for several fundamental reasons. Firstly, NZEB are aligned with several UN SDGs, especially those related to climate action (SDG 13), affordable and clean energy (SDG 7), sustainable cities and communities (SDG 11), and responsible consumption and production (SDG 12) [United Nations, 2015]. These buildings have a significant impact on reducing greenhouse gas emissions by minimizing energy consumption and maximizing the use of renewable energy sources, directly contributing to mitigating climate change (SDG 13). Additionally, by utilizing renewable energy sources, they promote access to affordable and clean energy (SDG 7) and foster the development of more sustainable communities by reducing dependence on fossil fuels and improving air and water quality in urban environments (SDG 11). Furthermore, by optimizing resource use and minimizing energy waste, NZEB support the goals of responsible consumption and production (SDG 12).

Secondly, the construction and operation of NZEB can also contribute to other SDGs such as good health and well-being (SDG 3) by providing healthier and more comfortable indoor environments, reducing poverty (SDG 1) by lowering energy costs for residents and users, and quality education (SDG 4) by serving as examples of sustainable practices that can be adopted and replicated in other projects. Moreover, promoting NZEB can stimulate technological innovation and economic development (SDG 9) by encouraging research and development of new technologies and sustainable construction practices, and strengthen partnerships for the achievement of goals (SDG 17) by involving multiple stakeholders, including governments, industry, academia, and civil society, in the planning, design, and implementation of NZEB projects.

Because of the large amount of CO2 emissions they release and the high energy consumption, the building sector has a fundamental role to achieve these goals. For this reason, several countries have developed projects and research on the Net Zero Energy Buildings (NZEB), which are those constructions that reduces their energy consumption by implementing energy efficiency measures, so the rest of the energy needs can be supplied by renewable technologies [Torcellini et al., 2006a].

The first thing that comes to mind when talking about a NZEB could be a building that produces the same energy that it consumes in a certain period, however, the use of energy is related to many aspects of a building beyond the amount of kWh it consumes or generates, such as the money spent in the consumption and earned for the generation or the CO2 emissions emitted or saved. Because this variety of relationships, a single definition is not enough to define what a NZEB is, so Torcellini et al. [2006a] developed four NZEB definitions: Net Zero Site Energy (site-NZEB), Net Zero Source Energy (source-NZEB), Net Zero Energy Costs (cost-NZEB) and Net Zero Energy Emissions (emission-NZEB). The four NZEB definitions are described below:

- To meet site-NZEB definition, the building's renewable generation must be equal or greater than the total energy consumption. A limitation of this definition is that source energy values of the fuels are not considered, it is the same one energy unit of electricity than one energy unit of natural gas, when is very well known that electricity generation and distribution process involves more energy than in natural gas.

- To meet source-NZEB definition, the building's renewable generation must be equal or greater than the total energy consumption, considering the energy losses for the energy transformation, transmission and distribution to the building site. In other words, in this definition the source energy values are considered.

- To meet cost-NZEB, the earned money by generating renewable electricity to the grid must be equal or greater than the spent money for the energy consumption in the building.

- Finally, to meet emission-NZEB, the building saving emissions for using renewable technologies must be equal or greater than produced emissions by using fossil energy sources.

1.2 Background of the research

In order to understand the importance of evaluating whether a building is zero energy, this section shows some background information on research that has been done at the international, national and local level. Most of the research in this section does not aim to evaluate the four NZEB definitions, but does point out the strategies implemented to reduce their energy consumption, their emissions and their operating costs, elements that clearly define the NZEB. Knowing the process they went through and the measures implemented could be essential for a building to acquire NZEB status.

1.2.1 NZEB research at international scale

The NZEB research that has been done in the world is primarily from European and North American countries (Canada and USA) and it focuses on making both residential and non-residential NZEB. Torcellini et al. [2006b] conducted a study of six buildings—Orbelin, Zion, Cambria, CBF, TTF, and BigHorn—to explore various aspects related to the design, construction, operation, and evaluation of modern low-energy commercial buildings. Each building served as a unique case study, yielding a list of lessons learned and specific recommendations tailored to its characteristics. These insights contribute to a repository of best practices, favorable design features, and technologies crucial for future construction endeavors while highlighting potential pitfalls to avoid.

In lighting, two main practices were implemented across the six buildings for energy-saving purposes. Firstly, daylighting design was utilized, strategically maximizing natural light access and minimizing electric lighting usage through features such as clerestories, elongated east-west axes, south-facing glazing, skylights, and sidelit and toplit daylighting. Secondly, daylight and lighting controls were employed, installing equipment to automatically adjust electric lighting based on natural light levels or occupancy status, including daylight sensors and motion sensors. Notably, Oberlin, Zion, TTF, and BigHorn saw significant lighting savings, representing the largest portion of total energy savings, ranging from 93% in the BigHorn warehouse to 30% at CBF. Moreover, natural ventilation emerged as a significant contributor to energy efficiency in four of the buildings, primarily for cooling and ventilation purposes. The substantial adoption of photovoltaic (PV) systems to meet NZEBs objectives was noted, with emphasis on proper PV panel positioning to avoid shading, as shading experienced by each PV array resulted in energy penalties ranging from 2% to 44% output reduction.

The research by Feng et al. [2019] aimed to delve into the development of NZEBs in hot and humid climates, focusing on 34 case study buildings to grasp the challenges and opportunities in achieving NZEB status in such regions. These buildings were carefully chosen worldwide, considering their energy performance data availability and alignment with the study objectives. Gathering comprehensive data on design features, energy-efficient technologies, and performance metrics, including architectural design, HVAC systems, lighting, plug load equipment, renewable energy technologies, and operational strategies, enabled a thorough analysis. Site energy balance calculations were performed based on annual energy consumption and renewable energy generation data.

Categorizing the design features and technologies into architectural design and envelope, HVAC, lighting, plug load equipment, and renewable energy technologies facilitated structured analysis, providing insights into their effectiveness in achieving energy efficiency and net zero energy goals, compared against standards such as those set by ASHRAE. Additionally, a review of global NZEB-related policies and standards contextualized findings within regulatory frameworks, evaluating the impact of supportive policies on NZEB adoption. The analysis uncovered significant energy savings in the case study buildings across various energy use categories, with an average site annual energy consumption intensity of less than 100 kWh per square meter of floor space. Some buildings even achieved "net-positive energy," generating more energy locally than they consumed. Remarkable energy savings percentages were observed in different energy use categories:

- Buildings with energy-efficient lighting solutions saved an average of 30% compared to conventional lighting systems,
- Energy-efficient appliances led to an average energy savings of 25%,
- Advanced lighting controls resulted in an average energy savings of 20% through optimized lighting usage,
- Implementation of air enthalpy heat recovery and hot water heat recovery systems yielded energy savings of 15% and 10%, respectively,
- Buildings employing displacement ventilation and radiant cooling systems demonstrated energy savings of 20% and 15%, respectively and
- Integration of renewable energy technologies like air source heat pumps and fans with evaporative cooling contributed to an average energy savings of 25% in the buildings.

The research conducted by [Shirinbakhsh and Harvey, 2021] aimed to compare the effectiveness of four widely-accepted definitions of NZEB in reducing operational greenhouse gas emissions. The study aimed to assess how different NZEB definitions impact the emission levels of buildings in two distinct cities, Toronto and Miami, with varying energy behaviours. By analysing the emissions reduction potential of each NZEB definition, the research sought to provide insights into the most efficient strategies for mitigating greenhouse gas emissions in buildings.

The research employed a comparative analysis approach to evaluate the impact of four main NZEB definitions on operational greenhouse gas emissions. A simple geometry located in Toronto and Miami was considered as the context for comparison. The study analysed the four NZEB definitions previously described. Two cases of energy source are proposed for the buildings: 1) Electricity and natural gas and 2) only electricity. Also two building uses are proposed: 1) Residential and 2) commercial. If the two cases of energy source are combined with the two cases of building uses, results the four following scenarios to assess the effectiveness of each NZEB definition in reducing emissions:

- Commercial with electricity and natural gas,
- Residential with electricity and natural gas,
- Commercial with electricity and
- Residential with natural gas.

The cost-NZEB definition was identified as the most effective in reducing greenhouse gas emissions, leading to the lowest overall greenhouse gas intensity levels in both Toronto and Miami. Reaching net-zero performance resulted in significant reductions in greenhouse gas emissions, ranging from 49% to 145% in Toronto and 89% to 117% in Miami, depending on the chosen NZEB definition. Different NZEB definitions had varying effects on emissions reduction, with the cost-NZEB definition demonstrating the highest efficacy in achieving negative or close-to-zero emission levels. The study highlighted the importance of considering the impact of the NZEB definition on operational greenhouse gas emissions when designing energy-efficient buildings, emphasizing the role of renewable energy systems in reducing emissions and enhancing building resiliency.

1.2.2 NZEB research at national scale

In Mexico, Morillón Galvéz and Ceballos Ochoa [2015] report that several projects have been carried out to investigate NZEBs, however, most of these are focused on residential buildings. This can be explained if it is considered that the final energy consumption for the residential sector is higher than that of the commercial (or non-residential) sector, 833.62 PJ (15%) and 141.24 PJ (3%) respectively [SENER, 2023]. For instance, Velázco Ruíz [2021] conducts an analysis comparing the environmental, energy, and economic impacts of sustainable against conventional building construction. The study aims to determine whether sustainable construction results in cost increases exceeding 15% compared to traditional methods. Three sustainable and three traditional housing models were proposed for comparison, with energy and thermal simulations conducted using EnergyPlus. Results show that the cost increase from the best-equipped sustainable model to the worst-equipped traditional model is 14.75%.

Morillón Galvéz and Ceballos Ochoa [2015] provide a brief summary of the projects that have been developed in Mexico to investigate NZEBs and among all those, only one has been focused on a non-residential building. In 2005, as a part of an investigation, a photovoltaic (PV) system interconnected to the grid was installed in The Green Corner, an organic store that is located in the south of Mexico City. Although it is not known with certainty if the store produced the amount of energy that it consumed in a year, it is considered to be, if not the only one, one of the few projects to investigate non-residential NZEBs that have been developed in Mexico until 2015. Despite the fact that several projects have been developed to investigate zero energy in residential buildings, the little amount of information about non-residential buildings is alarming.

When a country has done enough research and collected the necessary data, it is possible to start making NZEBs or retrofit existing buildings into one. In any case, the use of energy simulation programs is essential, since with these you can have a more approximate idea of the energy behaviour that the building will have while it is in operation and, therefore, assess whether it is a NZEB. Other countries have developed databases to benchmark building energy use based on climate, constructive systems, internal thermal loads, occupancy type and electrical grid, however, in Mexico, that information has not yet been determined and using the data of another country would not be appropriate.

In Mexico, there are more and more organizations that use construction regulations to make their buildings energy efficient and emission savers. One of those organization is National Autonomous University of Mexico (UNAM by its acronym in spanish), which account with several campus around the country. For instance, in September 2020, UNAM [2017] published a guide outlining technical, preventive, corrective, and safety measures for the construction and renovation of university buildings. The goal is to minimize environmental impact by harnessing natural resources sustainably. The guide aims to provide UNAM departments with directives for managing water and electricity efficiently throughout the project lifecycle, including construction and operation phases. It contains essential information regarding CU-UNAM buildings, including lighting levels, dimensions of sanitary and educational spaces, envelope characteristics, and relevant standards.

1.2.3 NZEB research at local scale

UNAM is aware that Mexico is one of the nations where renewable energies can have more opportunities to grow, which is why it has a Renewable Energy Institute (IER by its acronym in Spanish), a campus whose mission is to carry out basic and applied scientific research in energy, with an emphasis on renewable energies. Despite not being focused on the topic of NZEB in the IER, several investigations have been carried out on energy efficiency and renewable energy in buildings, fundamental components for NZEBs. López Sánchez [2018] analyses electricity consumption at the IER for enhancing energy efficiency. It includes updating the inventory of electrical loads, conducting precise measurements using specialized equipment, and examining electricity bills to understand costs and consumption trends. The methodology involves categorizing buildings and devices, using specialized equipment for accurate measurements, and examining bills thoroughly. Findings include successful categorization of devices, obtaining accurate consumption data, and identifying cost patterns. As a result of the research, a monthly energy consumption per person of 92.30 kWh/month was determined and the daily energy consumed by each building that he studied in his work. Crucial conclusions emphasize the importance of a comprehensive load inventory, accurate measurements, and maintaining updated records for ongoing efficiency improvements.

Currently, IER is constructing a new building with bioclimatic design and low energy systems for air conditioning. Although the new building at IER may appear to have elements that characterize a NZEB, the building was not specifically designed to be a NZEB. However, as mentioned above, it is important to start knowing the information needed to assess whether a non-residential building can be a NZEB, so the general objective of this thesis is to evaluate the NZEB definitions in the new building at IER-UNAM in Temixco. The specific objectives of this thesis are to provide a literature review about the concept of NZEB, to create a numerical model that simulates the energy consumption of the IER's new building, to determine the information required to evaluate the NZEB definitions in the IER's new building, to create scenarios based on an analysis of the numerical model and to evaluate the definitions in the created scenarios.

1.3 Net zero energy building concept elements

According to Sartori et al. [2012], the Figure 1.1 shows the most important elements that characterizes a NZEB.

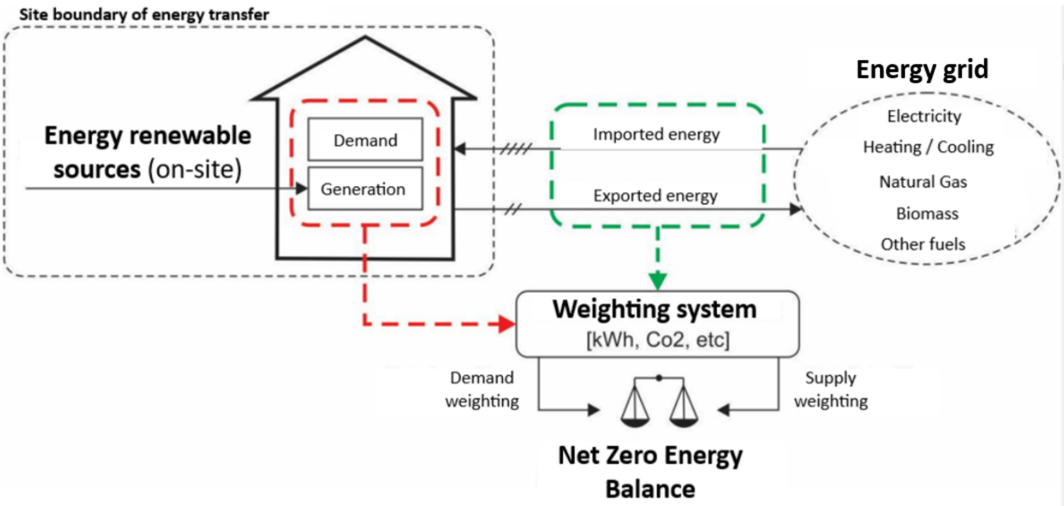


Figure 1.1: Graphic representation of the terminology used in a NZEB. Source: Translated from [Morillón Galvéz and Ceballos Ochoa, 2015], with information from [Sartori et al., 2012].

The description of each element is below:

- **Site boundary of energy transfer:** Limits for comparing energy flows entering and leaving the building.
- **Energy grid:** The external energy supply system, which can be electricity, natural gas, thermal, biomass or other fuel.
- **Imported energy:** Energy flow from the external grid to the building.
- **Exported energy:** Energy flow from the building to the grid.
- **Demand:** The energy consumption of the building.
- **Generation:** The energy generation by the building.
- **Weighting system:** Refers to converting units into other metric units; for example, convert energy use units (kWh) to emission units (tonCO2).
- **Demand weighting:** It is the sum of all the imported energy or consumption, it is obtained by adding all the energy loads multiplied by their respective conversion factor.
- **Supply weighting:** The sum of all the exported energy or generated is obtained by adding all the energy loads multiplied by their respective conversion factor.
- **Net Zero Energy balance:** To evaluate each of the NZEB definitions, it is necessary to make a balance between the consumption and the generation of the building (or between imported and exported energy). If the result of the balance is equal to or less than zero, the definition is met.

To assess compliance, each of the NZEB definitions uses a balance, as can be seen in Figure 1.1. For each of these balances, it is necessary to determine the period to be evaluated, the type of balance, and the units that will be used. In the period you can use the time interval of your choice, although usually a year is selected. According to Morillón Galvéz and Ceballos Ochoa [2015], within the types of balance are consumption-generation and import-export. The use of any of the two has the same result in the selected period, so either can be used. Lastly, through the weighting system, energy can be multiplied by a factor to transform it into other units, such as tons of CO2 or units of money.

1.3.1 Boundaries

On many occasions, buildings are constructed on land whose area is not fully occupied by the building (for example, a supermarket with a parking lot). In this land, the area occupied by a building and the area without buildings is known as the building site. The portion of the building site where the building is constructed is known as the building footprint. Therefore, a building site is made up of a building footprint and the area where no buildings are built.

Both, in the footprint of the building and in the area without buildings, there can be energy consumption and also renewable generation. Therefore, the site boundary could be the building footprint if the renewable technology is installed in a part of the building (the roof, for example) or could be the entire building site if the renewable technology is installed in the surface with no buildings (solar protection in the parking lot, for example). Finally, when the NZEB definitions are going to be evaluated, the building owner must decide what the site boundary will be.

1.3.2 Electricity grid connection

According with Torcellini et al. [2006a], a NZEB is a construction that uses efficiency gains in order to reduce the building's energy consumption so the rest of the energy needs can be supplied by renewable technologies. Therefore, a building disconnected from the grid could be NZEB if it satisfies its energy consumption with renewable generation in a certain period. This can be achieved with the use of batteries or with an adequate sizing of renewable technologies. However, these solutions usually represent a large financial investment for the owners. Therefore, to achieve NZEBs, the use of the electrical grid is recommended, since if there is no generation in the building or the consumption exceeds the generation, the missing energy is imported from the grid. Otherwise, when the generation exceeds the consumption, the excesses are exported to the grid and the electric company compensates the building with energy that it can use later.

1.3.3 Efficiency measures and renewable technologies

To achieve NZEB status, a building can satisfy its energy consumption with renewable energy of different sources (solar, wind, hydro, geothermal, biofuels and others) and with technologies installed off the building site, however, to reduce de environmental impact, Torcellini et al. [2006a] recommend that renewable generation is within the building site, as this means a reduction in energy losses from transportation and conversion, processes in which a great amount of $CO2$ emissions is released. Therefore, for a building to achieve NZEB status, on-site photovoltaic generation and on-site wind turbines generation are recommended. However, because of the structures that must be installed, the noise it causes and the availability of resources, it is not very common for buildings to produce wind energy. Therefore, solar PV was chosen as the main technology to produce renewable energy in this thesis. Table 1.1 shows, in order of preferred application, renewable energy supply options in the NZEB context.

Table 1.1: NZEB Renewable Energy Supply Option Hierarchy. Source: [Torcellini et al., 2006a].

Option number	**NZEB Supply-Side Options**	**Examples**
0	Reduce site energy use through low-energy building technologies	Daylighting, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, etc.
On-site Supply Options		
1	Use renewable energy sources available within the building's footprint	PV, solar hot water, and wind located on the building footprint.
2	Use renewable energy sources available at the site.	PV, solar hot water, low-impact hydro, and wind located on-site, but not on the building footprint.
Off-site Supply Options		
3	Use renewable energy sources available off site to generate energy on site	Biomass, wood pellets, ethanol, or biodiesel that can be imported from off site, or waste streams from on-site processes that can be used on-site to generate electricity and heat.
4	Purchase off-site renewable energy sources	Wind, PV or, sometimes, hydroelectric.

To achieve a zero energy balance more effectively, it is essential to prioritize energy efficiency measures first, followed by on-site renewable energy generation. Passive solar heating and daylighting are examples of common efficiency measures for achieving NZEB status. The owner of the building must always make sure that the efficiency measures implemented work during the time that the building is in operation, so that there is always an energy saving. The basic idea behind achieving NZEBs is that saving energy is much easier than generating energy through renewable technologies.

It is also recommended that the renewable technologies are installed within the building footprint, since if they are only installed within the building site (for example, photovoltaic modules in the parking lot), it is very likely that the natural resource used to generate electricity is limited at some point by changes in the nearby construction environment (for example, the shading of a photovoltaic module by a nearby object). For this reason, if the technology is installed in the footprint of the building (for example, photovoltaic modules on the roof) it is more difficult for a nearby construction to affect its operation.

Renewable sources such as wood pellets, ethanol, biodiesel, waste vegetable oil from waste streams and methane from human and animal wastes may be counted as renewable generation on the energy balance, however, they do not count as on-site renewable sources, since these materials are typically imported to the site.

The less recommended supply option includes purchasing renewable energy produced out of the building site, which is available to be transported, through the electrical grid, to the site. Buildings that use resources renewable energy sources available off site to generate energy on site and buildings that purchase off-site renewable energy sources to achieve zero energy are considered off-site NZEBs. Although becoming an off-site NZEB can have little to do with design and a lot to do with the different sources of purchased off-site renewable energy, an off-site NZEB is still the concept of a NZEB [Torcellini et al., 2006a].

1.4 Site energy and source energy

Peterson et al. [2015] describe the main differences between site energy and source energy, which are fundamental concepts to understand one of the NZEB definitions.

Site energy refers to the amount of energy consumed by a building as indicated in its utility bills. It provides information about the building's performance, but it doesn't provide a complete outlook of the environmental impacts resulting from an specific source consumption and associated emissions. In addition, site energy is not a reliable metric for comparing buildings with different energy mixes. Energy can be delivered to a building in two forms: primary energy or secondary energy. Primary energy refers to the raw fuel, like natural gas or fuel oil, that is used for generation of heat and electricity. Secondary energy, on the other hand, is the energy produced from a raw fuel, such as electricity from the grid. Comparing a unit of primary energy to a unit of secondary energy is not adequate since one represents a raw fuel while the other represents a converted fuel. Therefore, it is necessary to convert these energy types into equivalent units of raw fuel consumed to generate one unit of energy on-site. To achieve this equivalence, source energy is used.

Source energy calculations take into account the energy consumed during the extraction, processing, and transportation of primary fuels, as well as the energy losses incurred during thermal combustion in power generation plants, and the losses during transmission and distribution to the building site. In essence, source energy encompasses site energy and all associated energy losses (as can be seen in Figure 1.2). Source energy is calculated by multiplying adequate site to source energy conversion factors (StSF) to imported and exported energy, resulting in a total equivalent source energy. It is important to mention that StSF is a dimensionless value.

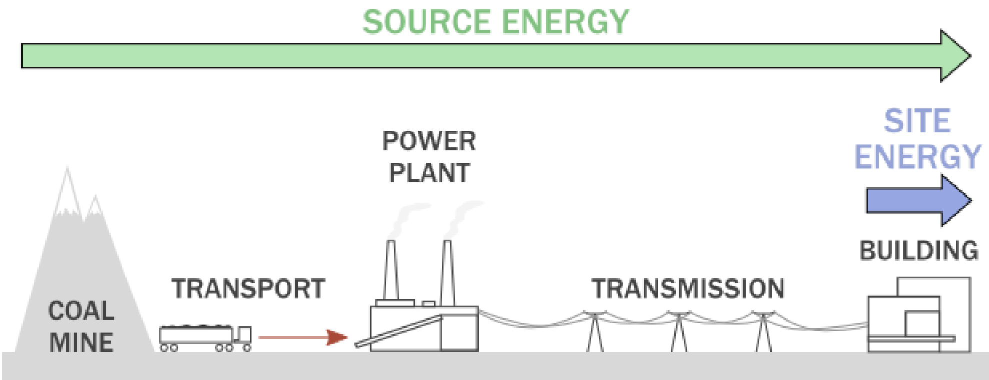


Figure 1.2: Difference between site energy and source energy. Source: Skwiot [2021].

Energy Star is a program of the United States Environmental Protection Agency (EPA) created in 1992 to promote electrical appliances with efficient electricity consumption, thus reducing greenhouse gas emissions from power plants [EnergyStar, 2013]. Another of the activities carried out in the program is the calculation of the site to source energy conversion factors (StSFs) for different energy types. Those factors are shown in Table 1.2 for United States and Canada.

Table 1.2: U.S. and Canadian StSFs by energy type. Source: [EnergyStar, 2013].

Energy Type	U.S. StSF	Canadian StSF
Imported electricity	2.8	1.96
Not exported renewable electricity (On-site solar or wind)	1.00	1.00
Exported renewable electricity (On-site solar or wind)	2.8	1.96
Natural Gas	1.05	1.01
Fuel oil (Diesel, Kerosene)	1.01	1.01
Propane and liquid propane	1.01	1.04
Steam	1.20	1.33
Hot water	1.20	1.33
Chilled water	0.91	0.57
Wood	1.00	1.00
Coal/Coke	1.00	1.00
Other	1.00	1.00

Electricity and gas imported to the site have to be multiplied by the corresponding StSF to calculate their source energy. However, when renewable energy is produced on-site, energy losses are close to zero, so a StSF of 1 is associated with it. When renewable energy is exported to the grid as electricity, it displaces electricity that would be required from the grid. In NZEB accounting, the exported energy is given the same StSF as the imported energy to appropriately credit its displacement of imported electricity and the same applies for a consumption-generation balance. In other words, the electricity company uses more energy to produce and transport a kWh of electricity than is used when the kWh is produced with renewable technologies on site, since in the second way there are no losses because of transformation and distribution. For the net zero energy balance, a renewable electric kWh is worth the same as a conventional electric kWh, despite the energy that the latter used is much larger. In order for the two kWh generated to be equivalent and to be able to be compared fairly in the balance, it is necessary that the renewable electricity is also multiplied by the same StSF as the electricity consumed.

1.5 Building energy simulation

NZEB definitions can be evaluated on buildings already built and on buildings not yet built. The latter refer to those that are planned to be built but are still in the design stage. It is easier for a building in the design stage to meet the NZEB definitions because, if the owner so wishes, a design can be implemented in the building that allows an efficient energy use and a good use of natural resources (sun and wind) to generate energy. However, to assess whether the definitions are met with the proposed design, it is required to have data on the building's energy consumption and renewable generation. As the building is not yet in operation, the only way to estimate this data is through an energy simulation of the building. For this, it is necessary to collect information such as the climate, envelope, occupancy, lighting, electrical equipment, gas equipment, air conditioning, number of floors, glazing, schedules (for occupancy and loads), refrigeration and others. If a proper energy simulation of the building is constructed, it will be possible to estimate the energy data of the building and assess whether the NZEB definitions are met or what changes need to be made.

On the other hand, in buildings already built, despite not having been built with the aim of meeting the NZEB definitions, they could still achieve it if they meet the necessary conditions. If a building is already in operation, the NZEB definitions could already be assessed, as energy consumption data could be obtained from bills and generation data could be obtained from renewable production systems. However, there may also be buildings already built that are not in operation, so it would not be possible to evaluate the NZEB definitions. In these cases, as with buildings not yet built, the only way is through an energy simulation. The energy simulation of a building basically consists of creating a model based on the relationship between the numerical values of the building's characteristics, so numerical model would be a more appropriate name and will be used from this point on.

Since it is a numerical model, it would be logical to think that it can be built in any spreadsheet such as Excel. However, there are some characteristics of the model that can only be created if specialized energy simulation software is used, such as EnergyPlus. The main example is the generation of renewable energy in the building. EnergyPlus allows you to create a surface of any size, shape, or orientation to simulate a photovoltaic system. When climatic variables are introduced to the simulation (such as solar radiation), the software can calculate the amount of energy that this system generates in a given period. Despite entering all the weather variables into Excel, this program could not calculate power generation with the ease that EnergyPlus does. EnergyPlus also allows you to add occupancy to the numerical model, calculate heat loads based on heating, ventilation, and air conditioning (HVAC) systems, calculate lighting levels for spaces and evaluate the thermal comfort of the occupants. All those elements could not be added in a data sheet, so everything that involves creating the numerical model of a building is much easier if it is done in specialized software.

What is sought when creating the numerical model of a building is that its energy behaviour is as similar to reality as possible. With this objective, there are two useful metrics to evaluate if the model is well done or has some irregularities. The two metrics are the electrical power density energy use intensity (EUI).

1.5.1 Electrical power density in buildings

Electrical power density refers to the amount of electrical power that is required per unit area in a space. It is typically expressed in watts per square meter (W/m^2). According with Venture Well [2018], electrical power density is an important measure because it can have several uses and benefits, such as:

- Energy efficiency: Monitoring electrical power density can help identify areas where energy consumption is high, allowing action to be taken to improve energy efficiency and reduce energy waste. This can lead to significant savings on your electricity bill and a lower environmental footprint.

- Design of electrical systems: Knowing the typical electrical power density of a space can be useful for the proper design of electrical systems in similar buildings. This allows you to plan the capacity of the electrical system and ensure that it is sized correctly to meet the power needs of the space.

- Electrical safety: Regular monitoring of electrical power density can help detect potential overload problems in the space's electrical system, such as overloaded outlets or circuits, which may be a sign of a fire hazard or short circuit. Identifying these situations in time allows preventive measures to be taken to guarantee the safety of the occupants.

- Regulatory compliance: In some locations, there may be regulations on the electrical power density allowed in different types of spaces. Staying within the established limits is important to comply with the regulations and avoid legal problems or penalties.

The electrical power density of a building is usually divided into lighting power density (LPD) and equipment power density (EPD). The first one refers to the electrical power for lighting that is used for each square meter in a space, while the second refers to the electrical power for equipment that is not gas or lighting, such as computers, cell phones, printers, televisions, coffee makers and others. Listed below are the methods for calculating LPD and EPD values in a space:

- Common: The power of the equipment or lighting systems that are consuming energy at that moment in space is added. The result is divided by the area of the space. If an organization uses this method to make a regulation, instead of calculating a value for a specific moment, it will establish a maximum value that must not be exceeded. In general, this maximum value is calculated by adding the powers of all the appliances that can be used in the space and not only those that are consuming energy at a specific moment, since this way they estimate the maximum electrical power density that a space could have under normal conditions. When these values are used in an energy simulation to obtain the annual energy consumption of a space, it is necessary to add schedules.

- Based on consumption: Annual energy consumption in a space by equipment or by lighting systems is calculated. The annual consumption is divided by 8760 hours, a value that corresponds to the hours in a year. Finally, the result is divided by the area of the space. The power density obtained from this method is somewhat different from the result of the previous method. To begin with, by dividing the annual consumption by the hours of the year, the power used in the space in each hour of the year is obtained. When these values are used in an energy simulation to obtain the annual energy consumption of a space, it is enough to multiply the value by the hours of the year and by the area of the space.

- Based on the lighting requirement: This method only applies to the calculation of lighting power densities and is the one used by organizations that make regulations. First you determine how much lighting is needed in the space. Luminance is measured in lux (lx) and represents the amount of light reaching a surface. One lx is equal to one lumen divided by square meter (lm/m^2). Then the luminance is divided by the lighting efficiency (depends on the technology used), which has units of lumen divided by watt (lm/W). The result is an LPD value that can be used as a standard for the design of the electrical system of a certain space. When these values are used in an energy simulation to obtain the annual energy consumption of a space, it is necessary to add schedules.

The use of each method has its advantages and disadvantages depending on the type of density that is calculated, this can be seen in the Table 1.3.

Table 1.3: Advantages and disadvantages of the methods to calculate LPD and EPD values.

Method	**LPD** [W/m^2]		**EPD** [W/m^2]	
	Advantages	**Disadvantages**	**Advantages**	**Disadvantages**
Common	• They can be used to design the electrical systems of the building.	• To use them in a numerical simulation, schedules are required, which are not always available. • Organizations do not use this method in their regulations.	• They can be used to design the electrical systems of the building. • Most of the organizations calculate the values with this method to put them in their regulations.	• To use them in a numerical simulation, schedules are required, which are not always available. • Values calculated by organizations are only presented by type of building and not by type of space.
Based on the consumption	• Schedules are not required in the energy simulations.	• They cannot be used to design the electrical systems of the building. • Organizations do not use this method in their regulations. • Lighting levels are not considered in its calculation.	• Schedules are not required in the energy simulations. • There are authors who have calculated these values by type of space.	• They cannot be used to design the electrical systems of the building. • Organizations do not use this method in their regulations.
Based on the lighting requirement	• Most of the organizations calculate the values with this method to put them in their regulations. • Its calculation considers adequate lighting levels for the space. • All the values are shown by type of space.	• To use them in a numerical simulation, schedules are required, which are not always available.	Does not apply	Does not apply

When someone is planning to make a building whose use of energy is efficient, it is recommended to create an energy simulation of the building, from which its LPD and EPD values can be obtained. To identify the areas of the building where energy consumption can be reduced, these values can be compared with normative values or with typical values of other buildings with the same use that were calculated by other authors. The method that each author or organization uses to calculate their LPD or EPD values depends a lot on the information and resources that are available, however, it is important to remember that the values can only be compared against others that have been calculated with the same method, since the considerations that are made in each one could be totally different.

However, it's important to consider that not all LPD and EPD values align with the intended electrical power density functions due to the calculation method used. For example, the values obtained through the method based on consumption can be used in energy simulations and compared with others to make the use of energy in the building more efficient, however, they cannot be used to design the electrical systems of the building, because the method calculates the average power that a space consumes in one hour of the year and not the actual power that is being used in the space. Another disadvantage of this method is that organizations do not use it to calculate their LPD and EPD values, so it is impossible to compare the calculated values.

The values calculated with the common method and the method based on lighting requirement can perfectly comply all the functions of the electrical power densities, however, not all of them have the same importance for the organizations that create the regulations. One of the organizations that has developed the most research on power densities is ASHRAE, however, almost all of these have been focused on determining lighting power density values for different types of spaces. That happens because lighting is usually one of the biggest energy end use in commercial and residential buildings. Therefore, focusing on light efficiency and LPD values is an effective way to reduce the total energy consumption of the building. Also, lighting technology has seen significant advances in recent decades, such as the widespread adoption of highly efficient LED lights. The focus on LPD allows to take advantage of these technological improvements and update the guidelines to reflect the latest trends in light efficiency. Finally, building standards and energy efficiency certifications, such as LEED (Leadership in Energy and Environmental Design), often emphasize lighting efficiency and require compliance with certain LPD values as part of sustainability criteria.

In almost all of its documents, ASHRAE uses the method based on the lighting requirement to calculate LPD values and the common method to calculate EPD values, however, for the equipment, they just show values for types of buildings (offices and academics) and not for types of spaces. A single EPD value cannot be used to make the electrical design of an academic building or to do an energy simulation, since the equipment power density is not the same in the different spaces of the building.

LPD values sources

ASHRAE [2022] provides information about typical LPD values in different spaces of an academic building. This document presents compliance pathways, which refer to methods and approaches used to meet the standards and guidelines established by ASHRAE regarding design, energy efficiency, and other aspects of HVAC systems, which help bring a building into compliance with US energy codes. The most common and relevant ASHRAE compliance pathways are prescriptive method and the performance rating method, each using different lighting power densities. The LPD values used in both methods are calculated using the method based on lighting requirement

The prescriptive method establishes specific and direct requirements that designers and engineers must follow to meet the energy efficiency and comfort standards established by ASHRAE. No numerical simulation is required and LPD values shown in the documents represent the maximum limit that must be considered in the design of the building. On the other hand, the rating performance method allows for a more flexible approach to standards compliance. Instead of following specific requirements, it focuses on evaluating the actual energy performance of a building through detailed analysis and simulations [ASHRAE, 2022] .

According with ASHRAE [2022], values for the performance rating method are typically higher for the following reasons:

- Design Flexibility: The performance rating method allows greater flexibility in determining LPD values. Rather than following strict and specific guidelines, as in the prescriptive method, this approach allows designers to select LPD values based on project needs and goals, as long as established performance criteria are met.

- Optimized energy efficiency: The performance rating method may take into account the application of more advanced and efficient lighting technologies and techniques, which could result in higher LPD values but reduced total energy consumption compared to the method prescriptive. By allowing more careful selection of light sources, light direction, and lighting control, it is possible to achieve a more efficient and sustainable design.

- Consideration of the specific context of the project: The performance rating method is based on the analysis of the actual performance of the lighting system in the context of the space and the needs of the user. This means that LPD values can be more precise and tailored to the unique characteristics of the project, which can result in more appropriate lighting allocation and, in some cases, higher LPD values to better meet requirements.

For example, to design a laboratory you could use the prescriptive method and set the maximum LPD value that ASHRAE allows. A disadvantage of using these values is that they are designed to provide adequate lighting in spaces with general laboratory activities (such as sample preparation, measurements, analysis and experimentation) and do not consider that there are laboratories whose activities are more specific and require a higher level of lighting. On the other hand, if this same LPD value is used but with the rating performance method, a simulation would be done to see if it meets the lighting requirements. If it doesn't, this method allows you to increase the LPD value a bit more so that this requirement is met. For this reason, the LPD values in this method are more flexible. Despite this advantage, the clearest obstacle is the complexity that may exist to collect the necessary data to carry out the energy simulation of the building, since information must be obtained on the lighting levels of the space, occupation and hours of use. Then the building designer must choose a method based on the availability of information and resources. Since the object of study of this research work is the new IER-UNAM building, the Table 1.4 shows the LPD value of the main spaces that make up an academic building.

Table 1.4: Lighting power density values from ASHRAE main compliance paths.

	Lighting power density [W/m^2]	
Space type	**Prescriptive pathway**	**Performance pathway**
Classroom	7.75	15.65
Office	6.03	11.84
Computer classroom	8.07	23.03
Kitchen	12.8	12.91
Corridor	4.73	5.38
Lobby	8.61	14
Laboratory	13.02	15.06
Study room	7.75	15.65
Computer service	7.85	16.14
Cafeteria	3.87	9.68
Restroom	7.96	9.68
Mechanical room	7.64	16.14
Parking lot	0.40	18.83
Rooftop	0.75	2.15
Exterior	0.75	2.15

EPD values sources

ASHRAE documentation does not have as much information for EPD as it does for LPD. The main reason could be that, the constant evolution of technology and the varied use that is given to it in different countries, does not allow ASHRAE to provide specific values that are universally applicable. Among the few documents that show information on EPD values of academic buildings, is ASHRAE [1989], which indicates that the maximum power density per equipment that can exist in a academic building is 5.4 W/m^2. The disadvantages of this value is that the considerations and methodology used to obtain it are never justified, in addition to the fact that the values are presented just for the type of building and not by space type. Although the details of this calculation are not known, it is likely that this EDP value was obtained from the common method.

A few years later, ASHRAE [2009] recognizes the importance of generating information about the electrical behaviour of equipment in buildings, so they establish 10.8 W/m^2 as the average EPD value for an office building. This approach has been widely used in the building construction sector for almost thirty years, because it contemplates a potential growth in the power of the equipment without introducing significant over design in building electrical systems [Wilkins and Hosni, 2011]. This value was also obtained from the common method.

Currently, almost all construction projects aim to use as little energy as possible and reduce their carbon footprint, so the equipment used is becoming more efficient and EPD values decrease. This change in the energy behaviour of new buildings and the generation of new information about EPD values is essential for NZEBs to become part of the current building construction model in the world.

Although the building construction sector has taken 10.8 W/m^2 as its main reference when designing a building's electrical system, this value was calculated for office buildings, so its use in any building that has other activities would not be adequate. In addition, the value is only shown by type of building and not by space, a detail that is essential to carry out more accurate energy simulations.

In the last decade several investigations have been developed to estimate EPD values in non-residential buildings. One of these works is from Mahajan et al. [2017], who estimated EPD values for each type of space in the Physics Plant Division of the University of California. From the 766 buildings that make up the university campus, only two were selected as objects of study, since these were the buildings that had the largest surface area of classrooms on the entire campus, in addition to having different types of space that characterize to an academic building. The first building was called Rinker Hall and the second Pugh Hall. It was assumed that both has the same space types (classrooms, office, computer rooms and other). Then, information was collected on the equipment that each space type has in both buildings, as well as its quantity and average power. The equipment that is considered for each space type in both buildings is shown in the Table 1.5.

Table 1.5: Equipment in each space type in the buildings.

Space type	**Equipment used**
Classroom	Desktop computers, audio equipment, answering machines, video projectors, DVD players and overhead projectors.
Office	Desktop computers, monitors, printers, scanners, lamps, answering machines, adding machines, fax machines, space heaters, minirefrigerators and pencil sharpeners.
Computer classrooms	Desktop computers, audio equipment, answering machines, video projectors, DVD players and overhead projectors.
Kitchen	Coffee maker, microwave, electric kettle, refrigerator or minifridge, toaster and blender.
Corridors	LCD TV and vending machines.
Lobby	Laptops.
Media Center	Desktop computers, printers, scanners, CD recorders, docked personal digital assistants, videocasette rewinders and DVD players.
Copy room	Copiers, multifunction devices, shredders, pencil sharpeners, staplers, and laminators.
Teaching laboratory	Laboratory equipment
Study room	Laptops
Conference room	Desktop computer, video projector, DVD player, and answering machine.
Computer service room	Computer service equipment.
Auditorium	Speakers, LCD TV, desktop computers, and video projectors.

Using this information, the consumption-based method is used to calculate an EPD value for each type of space in the building. This process is applied in both buildings (Rinker Hall and Pugh Hall), so two EPD values are obtained for each space type. Those two values are averaged and that results in only one EPD value for space type. Finally, the EPD values calculated for each type of space are compared with the value proposed by ASHRAE [2009], which indicates 10.8 W/m^2 as the reference EPD value in the building construction sector. Therefore, to compare their results, Mahajan et al. [2017] consider this value in each of the space types. The Table 1.6 shows a comparison between the values obtained from the Mahajan et al. [2017] and those from ASHRAE [2009].

Table 1.6: EPD comparison by space type.

	EPD [W/m^2]	
Space type	**ASHRAE (2009)**	**Mahajan (2017)**
Classroom	10.8	2.2
Office	10.8	4.3
Computer classrooms	10.8	2.7
Kitchen	10.8	15.1
Corridors	10.8	1.1
Lobby	10.8	0.2
Media Center	10.8	5.4
Copy room	10.8	7.5
Teaching laboratory	10.8	2.7
Study room	10.8	2.2
Conference room	10.8	1.1
Computer service room	10.8	15.1
Auditorium	10.8	0.3
Library	10.8	-
Multipurpouse room	10.8	-
Cafeteria	10.8	-
Restrooms	10.8	-
Mechanical	10.8	-
Gym	10.8	-
Main gym	10.8	-
Auxiliary gym	10.8	-

In conclusion, if an academic building is simulated energetically, LPD and EPD values can be obtained with the three methods described above, however, these values must be compared with others that have been calculated with the same method and whose information is available by type of space. To compare LPD values, the best option is to use the ASHRAE values, which are calculated with the method based on the lighting requirement and are presented by type of space. Therefore, the LPD values that are going to be compared must be calculated with the same method. To compare the EPD values, ASHRAE could be used again, however, its documents do not present the values by type of space, therefore, for academic buildings, it is recommended to use the values obtained by authors such as [Mahajan et al., 2017].

1.5.2 Energy use intensity for academic buildings

The other measure that can be used to assess the energy behaviour of the simulated building and make it as close to reality as possible is the energy use intensity (EUI), which, according with EnergyStar [2021] is an indicator of the energy efficiency of a building's design and/or operations. It is used in a number of different ways including to set a target for energy performance before beginning design, to benchmark a building's designed or operational performance against others of the same building type, or to evaluate compliance against energy code requirements. EUI varies with building type, which means that a hospital will have a higher EUI than a restaurant. It is calculated by dividing the total energy consumed in the building in one year by the total gross floor area of the building, which refers to the sum of the square meters of the floors of all the spaces within a building, including offices, lobbies, restrooms, equipment storage areas, mechanical rooms, break rooms and elevator shafts. Gross floor area does not include outside bays, docks or parking areas [Washington State Department of Commerce, 2021].

Not all equipment considered in the EUI calculation must necessarily be within the gross floor area of the building. Equipment and systems within this area are considered directly related to building operations and are therefore included in the EUI calculation. However, there is equipment that can be located outside the gross floor area but is still considered in the EUI calculation. Some common examples include heating, ventilation, and air conditioning (HVAC) systems, exterior lighting equipment and general services equipment, such as water pumps, waste water management systems or elevator equipment. In summary, although most of the equipment considered in the EUI calculation is generally within the useful area of the building, there are cases in which equipment located outside this space can be included. The inclusion of this equipment depends on its relation to the energy consumption of the building and the guidelines established by the applicable standards and regulations.

According with Kerdan et al. [2015], the annual energy consumption of the non-residential sector in Mexico is underestimated because all buildings with an installed power greater than 100 kW are considered part of the industrial sector. In their work, they estimate the annual energy consumption of the non-residential sector in Mexico. For this purpose they use the information available in the Mexican Electric Energy Saving Trust (FIDE), ASHRAE documents and Official Mexican Standards (NOM) to create numerical models of seven different types of non-residential buildings in Mexico: Hotel, office, school, hospital, restaurant, shopping centre and supermarket. In each of the building types it is assumed that there are the following end uses of energy: HVAC, lighting, refrigeration, lift and pumps, internal equipment, cooking and water heating.

Each model has the typical characteristics of a building in Mexico for its respective type of use. The characteristics of the numerical model of the school are shown in the Table 1.7, since it is the type of building that is analysed in this work.

Table 1.7: Characterization of the mexican non-domestic buildings.

Floor area (m^2)	7,500
No. of floors	3
Location	Urban/Rural
Construction	Masonry-Concrete block
Cooling equipment	Chilled water
External walls U-value (W/m^2 ^oC)	1.00
Roof U-value (W/m^2 ^oC)	0.64
Glazing area(%)	30%
Window U-value (W/m^2 ^oC)	5.7
Lighting load (W/m^2)	16
Equipment (W/m^2)	3-10
HVAC equipment COP	2.5
Refrigeration compressor COP	2.5
Water heating efficiency (%)	78-82%

From the numerical model, the EUI for the school was obtained. However, they consider that the energy consumption can change greatly depending on the climate where the building is found, so a EUI value for schools is calculated for which they consider the main climatic regions in Mexico: Temperate, hot-humid and hot-dry. They assume that climatic regions are defined by federal entity (state) and that each state corresponds to a single climatic region (as can be seen in Figure 1.3). Although this is generally not exact, this approximation allows for mapping from other data, which is generally provided at the state level.

Figure 1.3: Climatic regions in Mexico. Source: Lorentzen and McNeil [2020] with assumptions of Kerdan et al. [2015].

The EUI values obtained from the school numerical model are shown in the Table 1.8, by final use of energy and by climatic region.

Table 1.8: EUI values from the school numerical model by final use of energy and by climatic region.

EUI (kWh/m^2 year)								
	Electricity					Gas		
Climate	**HVAC**	**Lighting**	**Refrigeration**	**Lift and pumps**	**Equipment**	**Cooking**	**Water heating**	**Total**
Temperate	2.4	27.6	0.8	1.2	8.5	15.5	6.0	62
Hot-humid	49.2	40.3	0.8	5.0	2.9	9.5	4.0	111.7
Hot-dry	85.2	53.7	0.8	14.9	15.2	13.1	4.9	187.7

Chapter 2

Methodology to evaluate NZEB definitions

As mentioned in the first chapter, each NZEB definition has a balance that must be calculated to evaluate whether the building meets the definition. Each of the balances requires the use of different datasets to be calculated, however, there are two data that are used in all balances, those are the building's renewable generation and the energy consumption. Obtaining this information from a building that has already been built is relatively simple, since the information about renewable generation can be provided by the person who was in charge of installing the technology and the energy consumption can be easily consulted on the bills. But, how to obtain this data from a building that is not yet built? For this, a numerical model of the building can be made, from which all the necessary information can be obtained to calculate the balances of the NZEB definitions.

On the other hand, one of the characteristics of the NZEB is to use efficiency measures to reduce the energy consumption. Although many of these measures can be applied when the building is already built, there are a greater number of measures that can be simulated in the design stage to evaluate their effect on the building, such as the implementation of a renewable generation system, an efficient lighting system, efficient HVAC systems, the building envelope, among other. Therefore, creating these numerical models allows us to consider a bioclimatic design, which includes elements such as orientation with respect to the sun, passive heating and cooling strategies, as well as natural lighting. Contemplating all these measures from the design stage of a building could significantly reduce the energy consumption, so covering it with the use of renewable energy would be easier, as it would be for the building to achieve any of the NZEB definitions.

In order to create this numerical model, EnergyPlus is used. This is an energy simulation program for whole buildings used to model energy consumption, renewable energy generation and building thermal performance through the use of a time-dependent heat transfer model. In this software you can add materials, construction systems, loads for electric equipment, lights and people, HVAC systems, as well as occupancy and temperature schedules.

It is important to mention that, although there may be many technologies from which renewable energy can be obtained (wind, geothermal, hydro, biomass, etc.), this thesis methodology only contemplates the use of photovoltaic solar technology.

This chapter gives the steps to follow to evaluate the NZEB definition in a building. First, at least one NZEB definition must be chosen to evaluate in the building of interest. Subsequently, the necessary information must be collected to build the numerical model of the building and to solve the balances of the NZEB definitions. Once the numerical model has been built and the simulation has been carried out, data series with information about three variables of the building will be obtained: electricity consumption, natural gas consumption and renewable generation. Depending on the type of balance used to calculate the definitions, these series can have data from one day to one year. In a data series, each moment where a variable data is collected is known as a time step. Then the interval between each time step must be selected in the simulation programme. With the information obtained from the numerical model, the balances of the NZEB definitions are calculated, the criteria to meet each of the definitions that were selected are reviewed and an analysis of the results obtained is made.

The steps to evaluate NZEB definitions in a building are: Selection of the NZEB definition (Section 2.1), data collection to built the numerical model and to solve the balance of the NZEB definitions (Section 2.2), creation of the numerical model in EnergyPlus (Section 2.3) and the analysis of the results and review of criteria (Section 2.4).

In order to improve understanding of the methodology for evaluating NZEB definitions in a building, a diagram summarizing each of the steps is shown in Figure 2.1.

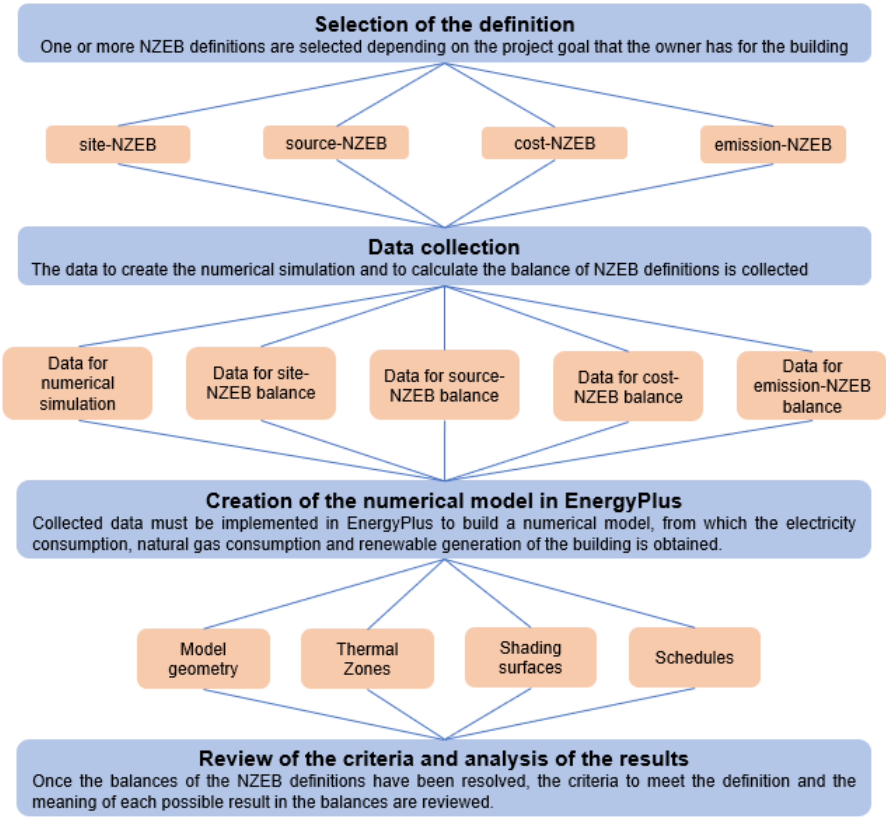


Figure 2.1: Methodology diagram.

2.1 Selection of the NZEB definition

There exists four definitions that can be evaluated in a building: site-NZEB, source-NZEB, cost-NZEB and emission-NZEB. The first step is select one or more definitions depending on the project goal that the owner has for the building. Each NZEB definition has a balance that must be satisfied to achieve the definition.

As the NZEB definitions can be evaluated in any building that has some kind of energy consumption, then, it is possible to modify the fuels included in the balance, however, this implies that all the required information about added fuels must be collected first to calculate the balance. Although there are different sources of primary energy (coal, firewood, liquefied petroleum gas, and natural gas) and secondary (electricity and petroleum-derived fuels) that could be used in a building, Torcellini et al. [2006a] only consider the use of electricity and natural gas in the NZEB definitions balances, as they consider them as the most typical sources in a building. This also happens in the new IER building, so only the use of those two fuels will be considered to calculate the balances of the NZEB definitions.

On the other hand, it is also necessary to choose the type of balance with which you will work. As mentioned in the first chapter, there are two types of balances: import-export and consumption-generation. The choice of the balance depends on the owner's preferences. In this thesis work the consumption-generation balance was selected. In addition, one year was chosen as the period of the balance. Once those details about the balance are determined, the equations are as follows.

The balance that needs to be satisfied to achieve site-NZEB is

$$(Elec + NG) - (GEN_{ren}) \leq 0, \tag{2.1}$$

where

- GEN_{ren} is the total energy generated by the renewable energy system in a year [Wh],
- $Elec$ is the energy consumed in form of electricity [Wh] and
- NG is the energy consumed in form of natural gas [Wh].

The balance that needs to be satisfied to achieve source-NZEB is

$$(Elec \times StSF_{Elec}) + (NG \times StSF_{NG}) - (GEN_{ren} \times StSF_{Elec}) \leq 0, \tag{2.2}$$

where

- $StSF_{Elec}$ is the Site-to-Source Factor of electricity [-] and
- $StSF_{NG}$ is the Site-to-Source Factor of natural gas [-].

The balance that needs to be satisfied to achieve cost-NZEB is

$$\sum_{i=1}^{n}(Elec_i^{Dem} - Elec_i^{Gen}) \times Price_{Elec_i} + EAC + NG\ Costs \leq 0, \tag{2.3}$$

where

- n represent the total quantity of timesteps in the year,
- i represent the timestep in the year [-],
- $Elec_i^{Dem}$ is the electricity consumed for each timestep in the year [kWh],
- $Elec_i^{Gen}$ is the renewable electricity generated for each timestep in the year [kWh],
- $Price_{Elec_i}$ is the price of electricity for each timestep in the year [$/kWh],
- EAC is the Electricity Additional Costs, which represent the annual money spent in the permissions for using the grid [$] and
- $NG\ Costs$ is the amount of money spent for the use of Natural Gas in one year [$].

The balance that needs to be satisfied to achieve emission-NZEB is

$$(\frac{Elec \times AEF_{Elec} + NG \times EF_{NG}}{DCF \times AEF_{Elec} + (1 - DCF) \times MEF_{Elec}}) - GEN_{ren} \leq 0, \tag{2.4}$$

where

- AEF_{Elec} is the electricity average emission factor [tCO2/Wh],
- EF_{NG} is the natural gas emission factor [tCO2/Wh],
- DCF is the directly consumed fraction [-], which is the renewable energy directly consumed in the building over the total renewable generation, and
- MEF_{Elec} is the electricity marginal emission factor, which refers to the rate at which emissions would change with a modification in technology (renewable or conventional) to produce the energy that a person uses [tCO2/Wh].

Within the four NZEB definitions, there are three that use energy units (site-NZEB, source-NZEB and emission-NZEB). If the result of these three balances is equal to zero, GEN_{ren} can be isolated to calculate the renewable energy that needs to be generated to meet the definition. In the case of cost-NZEB, an iterative method needs to be implemented to calculate the renewable energy needed to meet the definition.

2.2 Data collection

Once the NZEB definition is selected, it is necessary to collect all the data to create the numerical simulation, to calculate the power of the natural gas equipment and to calculate the balance of the four NZEB definitions.

2.2.1 Data for the the numerical simulation

In order to built the numerical simulation, it is necessary to collect the following information about the building:

- Building plans,
- Weather data to build EnergyPlus weather file (EPW),
- Materials and construction systems,
- Number of people using the spaces,
- Electric equipments per zone and their power,
- Natural gas equipments per zone,
- Lights per zone and their power,
- Infiltration and ventilation,
- Air conditioning systems and their power,
- Occupancy, lights, electric equipment and natural gas schedules,
- Temperature set points,
- Area available to install the photovoltaic modules and
- Cell efficiency of photovoltaic modules and inverter efficiency.

2.2.2 Natural gas equipment power calculation

Both electricity and natural gas consumption can be calculated in EnergyPlus by creating loads for all equipment that uses these sources to operate. To create both types of loads, you need to enter the power of the equipment. However, unlike electric equipment, natural gas equipment usually does not have information about its power, since these equipment consist of containers that can be filled with a certain amount of natural gas in kg. Therefore, the expression to calculate the power that must be entered into a gas equipment in EnergyPlus is

$$EP_{NG} = \frac{P_{NG} \times CV_{NG} \times 1h}{\rho_{NG} \times HUPY \times 3600s}, \tag{2.5}$$

where

- P_{NG} is the LP gas consumption per year $[kg]$,
- CV_{NG} is the calorific value of natural gas $[J/m^3]$,
- ρ_{NG} is the density of natural gas $[kg/m^3]$ and
- $HUPY$ are the LP gas equipment hours of use per year $[h]$.

2.2.3 Data required for site-NZEB balance

Because it is the simplest definition, in order to calculate the balance, only the following elements are needed:

- Total annual electricity consumption in the building.
- Total annual natural gas consumption in the building.
- Total annual renewable generation in the building.

2.2.4 Data required for source-NZEB balance

All Site-to-Source Factors (StSF) must be specific to the country where the building is located. Unfortunately, very few countries in the world have developed studies about their corresponding StSF. Among these countries are the United States and Canada, which already have StSF values of electricity and natural gas for their respective territories. Energy Star is a program run by the US Environmental Protection Agency (EPA) and the US Department of Energy (DOE) and one of its tasks is to determine the value of StSF for those countries. This company has documentation that contains all the equations used to obtain the factors [EnergyStar, 2013]. Ideally, StSFs should be calculated for the location of the building of interest, however, it is very likely that, even with the documentation provided by EnergyStar, no information is available to calculate the values. Then, as a starting point, the values for the United States can be used, which are 2.8 for imported electricity, 2.8 for exported renewable electricity and 1.05 for natural gas.

2.2.5 Data required for cost-NZEB balance

To calculate this balance it is important to understand how the building electricity tariff scheme works. The price of electricity changes throughout the year, so, in order to calculate how much will be paid in a year for the building's electricity consumption, a balance between the electricity consumption and the electricity generation for each time step is made and then the result it is multiplied by the price of electricity at that time of year. The hourly tariff by region for each month $[\frac{\$}{Wh\ per\ hour}]$ is needed from the tariff scheme in order to calculate the total payment for electricity in one year.

Once the annual payment for electricity is calculated, additional costs of electricity are added, however, these costs are not the same for all countries, so it is a fundamental task to investigate what the additional costs are for the country where the building is located. According with CFE [2022], the additional electricity costs for Mexico are the following:

- Distribution: This cost refers to the delivery and distribution of electricity from the transmission grid to your home or business. It includes the expenses for maintaining and operating the lines and equipment that bring electricity to your location.
- Capacity: This charge is related to the capacity of the electrical grid to meet the maximum consumption for electricity in your area. It is a fee based on the amount of electricity you are set to consume in a specific period.
- Maximum Demand: It is the maximum amount of electricity you have consumed in a specific time period. This value is used to calculate capacity charges and reflects the highest peak of consumption.
- Fixed Charge: This is a constant cost that you have to pay regardless of the amount of electricity you consume. It is typically a basic fee for having access to the electrical service.
- Voltage Drop: It reflects the energy losses that occur when electricity is transmitted from the generating plant to your location. You may receive a bonus if your electrical installations are more efficient and have fewer losses.
- Total Bonus: This is a discount or credit that you can receive on your electricity bill. It may be related to energy efficiency or responsible electricity usage.

These additional costs can be found on the CFE electricity bill, while the online portal shows the methods to calculate them [CFE, 2022]. Finally, natural gas costs in the building are added to the balance, so it is also important to collect information about the natural gas tariff scheme in the country the building is located.

2.2.6 Data required for emission-NZEB balance

On a typical day, a NZEB only consumes a fraction of the electricity generated by the renewable technologies and the rest is sent to the electricity grid. That fraction represents the directly consumed fraction, whose expression is

$$DCF = \frac{DCRE}{TREG}, \tag{2.6}$$

where

- $DCRE$ is the directly consumed renewable electricity [Wh] and
- $TREG$ is the total renewable electricity generated [Wh].

When in a NZEB, there is electricity consumption and renewable generation at the same time, the latter may satisfies the consumption. The energy used to satisfy this consumption will be known as directly consumed renewable electricity.

Obtaining the following data is also essential for calculating the emissions balance:

- Electricity average emission factor [tCO2/Wh],
- natural gas emission factor [tCO2/Wh] and
- electricity marginal emission factor, which is a measure used to estimate the environmental impact of producing an additional unit of electricity in a specific location or at a specific time [tCO2/Wh].

It should be noted that these three data are not the same for all countries, so the information that corresponds to the country where the building is located should be investigated.

2.3 Creation of the numerical model in EnergyPlus

Once all the important information of the building has been collected, it must be implemented to build a numerical model in EnergyPlus, from which the electricity consumption, natural gas consumption and renewable generation of the building is obtained. To build the numerical model, the following steps are carried out:

- The dimensions of the building are used to create the geometry in a modeling program, which must be connected to EnergyPlus.
- Thermal zones are assigned to spaces in the building.
- A shading surface is created with the same area of the photovoltaic array that will be installed in the building. The cell efficiency of the modules is assigned to this element.
- An EPW must be inserted in the energy simulation program with the data of the climatological variables representative of the place where the building is located.
- The materials are added by entered their physical properties and dimensions.
- With the materials, the construction systems are created and these are assigned to each surface (walls, ceilings and floors) and subsurface (windows) in the building.
- A load definition is created for each type of electric equipment, lights and gas equipment in the building.
- The type and quantity of loads corresponding to each space in the building is placed.
- A dimensionless schedule is created for each of the load types and then is assigned to its corresponding load.
- Gas consumption, electricity consumption and renewable generation are selected as output variables of the numerical model.

Once the numerical model is finished, the simulation is run and data series of the output variables are obtained. From these series, the total annual consumption of electricity ($ELEC$) and natural gas (NG) in the building are obtained, as well as the total annual renewable generation (GEN_{ren}). Once these data and the others that are specific to each definition are obtained, the result of the balances of each NZEB definition is obtained.

2.4 Review of criteria and analysis of the results

Once the balance of each NZEB definition is solved, it is necessary to review the criteria to achieve the definition and the meaning of each possible result in the balances, whether positive, negative or zero.

- **site-NZEB:** To meet site-NZEB definition the building's renewable generation must be equal or greater than the total energy consumption. If the result of the balance is zero, the building generates the same renewable energy that it consumes, so the definition is achieved. If the result is more than zero, the building consumes more energy than it generates, so the definition is not achieved and more generation is necessary to meet it. Finally, if the result is less than zero, the building generates more energy that it consumes, so the definition is achieved and there is an excess of generation.

- **source-NZEB:** To meet source-NZEB definition, the building's renewable generation must be equal or greater than the total energy consumption, considering the energy losses for the energy transformation, transmission and distribution to the building site. The meaning of the results is the same as with the site-NZEB balance.

- **cost-NZEB:** To meet cost-NZEB, the earned money by generating renewable electricity to the grid must be equal or greater than the spent money for the energy consumption in the building. If the result of this balance is zero, the owner of the building doesn't receive any economic compensation for the renewable energy generated, but also doesn't pay anything for the energy consumed in the building, so the definition is achieved. If the result is more than zero, the owner pay an amount of money for the energy consumed in the building, so the definition is not achieved and more renewable generation is needed to meet it. Finally, if the result is less than zero, the owner doesn't pay anything for the energy consumptions in the building, so the definition is achieved and there is an excess of renewable generation, which means that the owner has a certain economic compensation.

- **site-NZEB:** To meet emission-NZEB, the building saving emissions for using renewable technologies must be equal or greater than produced emissions by using fossil energy sources. If the result of the balance is zero, the building saves the same CO2 emissions that it generates by the consumption of conventional energy sources, so the definition is achieved. If the result is more than zero, the building generates more CO2 emissions than it saves with renewable generation, so the definition is not achieved and it is necessary more generation to meet it. If the result is less than zero, the building saves more CO2 emissions than it generates by the consumption of conventional energy sources.

At this point it is possible to know which were the NZEB definitions that the building met and why it could not have met some others. If the building owner evaluates two or more NZEB definitions, these can be compared through the Renewable Energy Ratio (RER). This tool plays a crucial role in assessing feasibility, indicating the proportion of renewable generation relative to the total site energy use ($TSEU$). This ratio can also be seen as the percentage of annual consumption offset by renewable energy. Think about two hypothetical buildings: one trying to be an site-NZEB, and the other going for source-NZEB. By calculating the RER for both buildings, we can assess how easily each one could achieve its goal. A high RER means a lot of renewable energy, getting the building closer to the NZEB goal. When the RER is 1 (or 100%), it means all the renewable energy the building makes in a year covers its energy needs for that same period.

Each of the NZEB definitions has a minimum RER value (RER_{min}) that buildings must have to meet the definition. The general expression to calculate that minimum value is

$$RER_{min} = \frac{REN_{gen}}{TSEU}, \tag{2.7}$$

where REN_{gen} is the minimum annual renewable generation that a building must have to meet a specific NZEB definition.

There are some NZEB definitions whose RER_{min} value is easier to achieve than others. For example, to meet site-NZEB and source-NZEB it is necessary that the annual renewable generation (REN_{gen}) is the same as consumption of the building ($TSEU$). Therefore, if equation 2.7 is used to calculated the RER_{min} of those definitions, the result will be a $RER_{min} = 1$ (or 100%). On the other hand, for the RER_{min} values of cost-NZEB and emission-NZEB, the calculation is not something trivial and it will be reviewed in the next section.

In total four values of RER_{min} must be calculated, one for each NZEB definition. These values can be used as a reference to compare against the actual RER of a building and see how far it is from meeting the definition. To make a better comparison, the actual RER of a building will be represented by the RER_{real} symbol, while the minimum RER that a building needs to have to reach a specific definition will be represented by the RER_{min} symbol. Finally, it is important to clarify that NZEB definitions with smaller RER are easier to reach, and the amount of money that must be invested in renewable technologies is less.

Chapter 3

Study case

In accordance with the methodology of the previous chapter, to evaluate the NZEB definitions in any building it is essential to develop a numerical model from which its consumption and generation can be obtained. In this chapter, a case study is created with the new IER building, in which all the elements necessary to build the numerical model are described.

Section 3.1 provides a brief description of the new IER building, as well as all the interior and exterior spaces that comprise it. Schedules for all spaces in the building are also shown, as well as assumptions made for spaces without defined schedules of occupancy. This section also shows the working and holiday periods for the student section and for the non-student section. Finally, all information on the loads that consume energy in the building, such as electrical equipment, lighting and gas, is showed. Section 3.2 explains the use of SketchUp to build the geometry of the building and the details that have to be adjusted in EnergyPlus to create the numerical model of the building. Finally, in Section 3.3 the results of the numerical model are discussed. The behaviour of the energy use intensity (EUI) in the building and the power density in the different space types are analysed.

3.1 Description of the building

The building is part of the IER-UNAM, located in Temixco, Morelos. In the date this thesis is being written, the building is in the last stage of construction and has no occupation. The building was originally planned to have a parking lot, a ground floor (also named as floor 0) and two floors, as can be seen in the Figure 3.1). However, because of external situations, only the parking lot, the ground floor and the first floor were built. However, for this study case the complete project will be taken and second floor will be considered too.

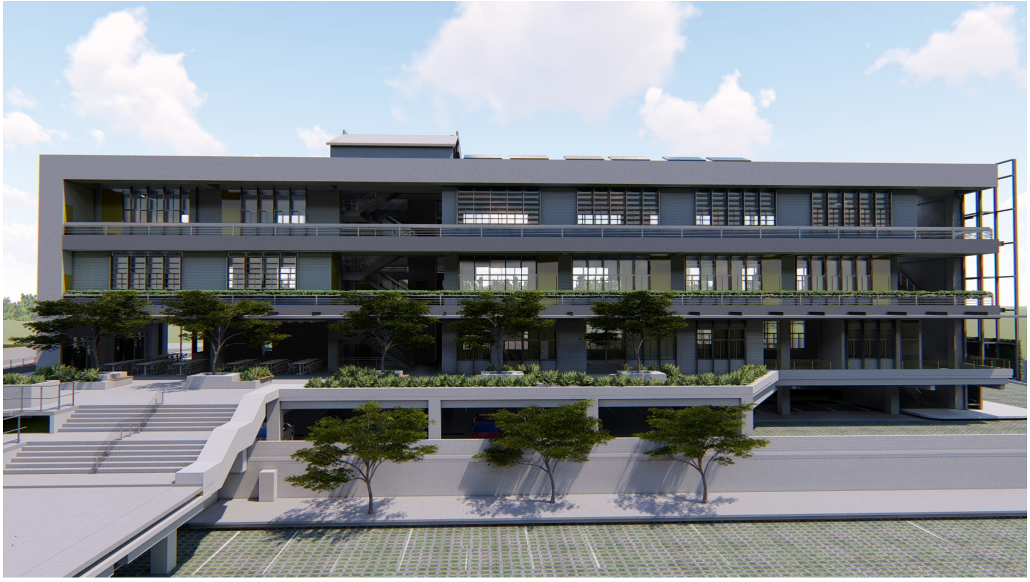


Figure 3.1: Render of south view and access plaza to the building.

The building has a construction footprint of 844 m^2 and a rectangular base. Moreover, solar protections are implemented on both the North and South façades. The building has a total of 30 spaces. On the ground floor are all the administrative spaces, the kitchen, the cafeteria, a work room, a computer room, the 3D printing room, the teacher's room, the meeting room, a lobby and a restroom, which does not have a defined occupancy. On the first floor are the four bachelor classrooms with the largest capacity, a laboratory and a restroom. Finally, on the second floor there are two laboratories, a work room, a restroom, three classrooms on the north side and three classrooms on the south side.

Table 3.1 shows all the spaces in the building grouped by floor. It also shows their space types, maximum capacity (Max_{cap}) and floor areas. The last column shows the code name to easily identify each space. All code names start with the floor where the space is located, Ground floor (F0), Floor 1 (F1) and Floor 2 (F2), and then a keyword is added to identify them. In the case of classrooms, after the keyword, the maximum capacity and a serial number are added.

Table 3.1: Description of spaces of the building specifying space name, space type, maximum occupancy, floor area ad code name.

Space name	**Space type**	Max_{cap}	**Floor area** [m^2]	**Code name**
Kitchen	Kitchen	4	63.41	F0kit
Cafeteria	Cafeteria	100	137.63	F0Cafe
Work room	Work room	25	90.10	F0Work
Coordination office	Office	1	24.15	F0Coor
Administration office	Office	3	82.77	F0AdmOff
COFI support office	Office	1	19.02	F0SuCOFI
COFI coordination office	Office	1	9.98	F0CoorCOFI
3D print room	3D print room	1	16.62	F03DPr
Computer classroom	Computer classroom	21	75.54	F0Comp
Meeting room	Meeting room	5	27.97	F0Meet
Teacher's lounge	Teacher's lounge	2	25.02	F0Teach
Lobby	Office	1	12.5	F0Lobby
Restroom	Restroom	-	18	F0Rest
Classroom	Classroom	41	77.73	F1Cr411
Classroom	Classroom	41	85.05	F1Cr412
Classroom	Classroom	41	80.24	F1Cr413
Classroom	Classroom	41	80.94	F1Cr411
Laboratory	Laboratory	21	201.04	F1Lab
Restroom	Restroom	-	18	F1Rest
Classroom	Classroom	11	35.11	F2Cr111
Classroom	Classroom	11	38.41	F2Cr112
Classroom	Classroom	11	36.24	F2Cr113
Classroom	Classroom	21	44.48	F2Cr211
Classroom	Classroom	21	48.68	F2Cr212
Classroom	Classroom	21	45.92	F2Cr213
Corridor	Corridor	-	51.85	F2Corr
Work room	Work room	40	97.90	F2Work
Laboratory	Laboratory	21	81.35	F2Lab1
Laboratory	Laboratory	21	81.95	F2Lab2
Restroom	Restroom	-	18	F2Rest

When energy simulations are made, it is necessary to know the occupation of the spaces. For example, if you want to calculate the electrical energy consumption of a classroom in a three-hour session, it could be assumed that each person uses their computer for two hours. To calculate consumption, the occupancy is multiplied by the average power of a computer and by the two hours of use. It is in these situations where knowing the occupancy is very useful. The only detail is that, in real life, occupations are not always constant. Despite the fact that a classroom is designed for 41 people, it is possible that some days only 30 come. For this reason, for energy simulations, it is appropriate to assume that the maximum occupancy with which the spaces were designed is always constant. The only spaces that do not have a maximum occupancy is the corridor and the restrooms, since those are places where people are always passing by, so it is difficult to make estimations. The lobby of the new IER building has a small office, where there is a person who receives visitors, therefore an office space type is attached to it.

The bachelor's school includes several subjects that are taught over four years and each one is assigned a space. These spaces are called base classrooms. F1Cr411, F1Cr412, F1Cr413 and F1Cr414 are assumed as base classrooms. Of the 41 occupants of each base classroom, 40 are students and the remainder is the teacher. When the 40 students are not in the base classroom, they are distributed in the rest of the spaces(other classrooms, laboratories, and the computer room) to take other classes. It is assumed that when a space has a certain occupancy, this will be the maximum occupancy of the space and not intermediate quantities. For example, in the bachelor base classrooms, the maximum occupancy is 41 people, so when there are classes in one of these spaces, it will be considered that there are always 41 people inside the space.

On the other hand, there are other spaces that have different roles than teaching or administration and that have little occupancy, but represent a significant contribution to the building's energy consumption. Table 3.2 shows all these spaces, as well as their space types, floor areas and code names. Most of the energy consumed on the rooftop, parking lot, and outdoor spaces is from lighting. The computer service room and the mechanical room have loads of both lighting and electrical equipment. The computer service room is designed to house and manage computer systems, servers, networking equipment, and other critical infrastructure necessary for the operation of an organization's IT services and applications. The mechanical room contains essential systems that provide heating, ventilation, air conditioning, plumbing, and electrical services to the entire building.

Table 3.2: Description of other spaces of the building specifying space name, space type, floor area and code name.

Space	**Space type**	**Floor area [m^2]**	**Code name**
Computer service room	Computer service room	16	CompServ
Mechanical room	Mechanical room	252	Mech
Rooftop	Outdoors	575	Roof
Parking lot	Outdoors	2475	ParkLot
Exteriors	Outdoors	2745	Ext

No occupancy is assigned to the spaces of the Table 3.2, either because it is very low or because it is highly variable. However, all of these play a fundamental role in this work because of the great contributions they make to the energy consumption of the building.

According to the plans, the building has a footprint of 844 m^2, so it would be easy to assume that the total gross floor area is 2,532 m^2, a result that is obtained by multiplying the footprint by the three floors of the building. However, in the building plans there are spaces that were not included in the modelling of the building, so they are not included in the calculation of the total gross floor area and this turns out to be less than the previous result. These spaces were not included because they represent a very small portion of consumption for the building and increase the simulation time. In addition, there are other spaces that were removed from the final construction and are not considered for the calculation of total gross floor area. Finally, the building has an approximate total gross floor area of 1,993.6 m^2, which is integrated by the floor areas of all the spaces shown in the Table 3.1. From the Table 3.2 only the computer service room and the mechanical room are considered to be part of the total gross floor area.

3.1.1 Occupancy and schedule assumptions

For the numerical model and to evaluate the NZEB definitions, the determination of schedules is essential, since they allow a more realistic and precise modelling of the behaviour of energy systems over time. The schedules represent variations in energy consumption and supply throughout the day, week, or even year, reflecting typical patterns of energy consumption and production.

The class schedule that is considered to make the numerical model is shown in the Table 3.3. Code names of Table 3.1 are used to facilitate spaces identification and to compact the table.

Table 3.3: IER bachelor schedule, January-June semester

Space	Monday	Tuesday	Wednesday	Thursday	Friday
F1Cr411	8 am - 2 pm	8 am - 10 am 4 pm - 6 pm	8 am - 2 pm	8 am- 2 pm 4 pm - 6 pm	
F1Cr412	8 am - 2 pm	8 am - 2 pm		8 am- 12 pm	8 am - 2 pm
F1Cr413	12 pm - 2 pm	12 pm - 2 pm	12 pm - 2 pm	12 pm - 2 pm	
F1Cr411	8 pm - 12 pm	8 pm - 12 pm	8 pm - 12 pm	12 pm - 2 pm 4 pm - 6 pm	
F2Cr111	12 pm - 2 pm 4 pm - 6 pm	12 pm - 2 pm			
F2Cr112	12 pm - 2 pm 4 pm - 6 pm	10 am - 12 pm	12 pm - 2 pm	10 am - 12 pm	
F2Cr113		8 am - 10 am		8 am - 10 am	
F2Cr211	12 pm - 2 pm 4 pm - 6 pm		12 pm - 2 pm		8 am - 10 pm
F2Cr212		8 am - 11 am		8 am - 11 am	
F2Cr213		8 am - 11 am		8 am - 11 am	
F0Work					
F2Work					
F0Comp		12 pm - 2 pm 4 pm - 5 pm	4 pm - 5 pm	12 pm - 2 pm	
F1Lab		4 pm - 6 pm	8 am - 2 pm	12 pm - 2 pm 4 pm - 6 pm	
F2Lab1					8 am - 12 pm
F2Lab2		4 pm - 6 pm		4 pm - 6 pm	

The schedule in the Table 3.3 was provided by the bachelor's coordinator and corresponds to the semester of classes between

January and June. Since the simulation will be done for an annual period, it is assumed that this same schedule is used in the August-December semester.

The work rooms do not have assigned occupancy hours on any day of the week, since they are spaces designed for students to work in their free hours. During the schedule shown in the Table 3.3, students can connect their devices and consume energy in different spaces of the building, however, they can also do so outside of these schedule. Both the work rooms and the classrooms are spaces where students can spend their free hours, connect their devices and consume energy. Therefore, it is necessary to assign an occupancy schedule for the free hours to the work rooms and these four classrooms. As these four are the bachelor base classrooms, it is assumed that students spend all their free hours here and not in the other classrooms.

A survey was conducted with 22 bachelor students from different groups to collect information about the hours they stay in the current teaching building and the use they give to certain electrical equipment. Details about this survey are shown in Appendix A. With the data obtained, an average of the time at which the students left the teaching building was made and the result was 8 pm. Since the last class ends at 6 pm and students stay until 8 pm, it is assumed that the work rooms are used during this period, from 6 pm to 8 pm. On the other hand, classrooms are assumed to be used during free hours but before 6 pm.

The Table 3.4 shows the modified schedule with the free hours in the work rooms and in the classrooms on the first floor. To better identify the free hours, they are shown in red.

Table 3.4: IER bachelor schedule modified. January-June semester.

Space	**Monday**	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
F1Cr411	8 am - 2 pm **2 pm - 6 pm**	8 am - 10 am 4 pm - 6 pm **2 pm - 4 pm**	8 am - 2 pm **2 pm - 6 pm**	8 am- 2 pm 4 pm - 6 pm **2 pm - 4 pm**	**8 am - 6 pm**
F1Cr412	8 am - 2 pm **2 pm - 4 pm**	8 am - 2 pm **2 pm - 4 pm**	**8 am - 6 pm**	8 am- 12 pm **2 pm - 3 pm**	8 am - 2 pm **2 pm - 4 pm**
F1Cr413	12 pm - 2 pm **8 am - 12 pm** **2 pm - 4 pm**	12 pm - 2 pm **2 pm - 4 pm**	12 pm - 2 pm **2 pm - 4 pm**	12 pm - 2 pm **2 pm - 4 pm**	**8 am - 6 pm**
F1Cr411	8 pm - 12 pm **2 pm - 4 pm**	8 pm - 12 pm **2 pm - 3 pm**	8 pm - 12 pm **2 pm - 6 pm**	12 pm - 2 pm 4 pm - 6 pm **2 pm - 4 pm**	**8 am - 6 pm**
F2Cr111	12 pm - 2 pm 4 pm - 6 pm	12 pm - 2 pm			
F2Cr112	12 pm - 2 pm 4 pm - 6 pm	10 am - 12 pm	12 pm - 2 pm	10 am - 12 pm	
F2Cr113		8 am - 10 am		8 am - 10 am	
F2Cr211	12 pm - 2 pm 4 pm - 6 pm		12 pm - 2 pm		8 am - 10 pm
F2Cr212		8 am - 11 am		8 am - 11 am	
F2Cr213		8 am - 11 am		8 am - 11 am	
F0Work	**6 pm - 8 pm**	**6 pm - 8 pm**	**6 pm - 8 pm**	**6 pm - 8 pm**	**6 pm - 8 pm**
F2Work	**6 pm - 8 pm**	**6 pm - 8 pm**	**6 pm - 8 pm**	**6 pm - 8 pm**	**6 pm - 8 pm**
F0Comp		12 pm - 2 pm 4 pm - 5 pm	4 pm - 5 pm	12 pm - 2 pm	
F1Lab		4 pm - 6 pm	8 am - 2 pm	12 pm - 2 pm 4 pm - 6 pm	
F2Lab1					8 am - 12 pm
F2Lab2		4 pm - 6 pm		4 pm - 6 pm	

The rest of the spaces have constant occupancy schedules throughout the week, which are shown in the Table 3.5, along with their respective constant occupancy (Con_{occ}).

Table 3.5: Constant occupancy schedule of the other spaces in the new building.

Space	**Week occupancy schedule**
F0Kit	9 am - 6 pm
F0Cafe	9 am - 10 am 11 am - 1:30 pm 3:30 pm - 7 pm
F0Coor	9 am - 2 pm 3 pm - 7 pm
F0AdmOff	9 am - 2 pm 3 pm - 7 pm
F0SuCOFI	9 am - 2 pm 3 pm - 7 pm
F0CoorCOFI	9 am - 2 pm 3 pm - 7 pm
F03DPr	9 am - 2 pm 3 pm - 7 pm
Lobby	9 am - 2 pm 3 pm - 7 pm
F0Meet	10 am - 2 pm 4 pm - 7 pm
F0Teach	10 am - 2 pm 4 pm - 7 pm

The previous schedules correspond to the working period of the year, however, it is well known that academic buildings also have holiday periods, in which the building's occupancy decreases considerably, so the same happens with energy consumption. Therefore, it is also essential to define the holiday periods of the new IER building, since these are also used to make the annual schedules of the numerical model. Figure 3.2 shows the annual calendar for the 2022-2023 semester of the UNAM, which shows the work and vacation periods of the student section and the administrative section, which includes teachers and those in charge of the kitchen.

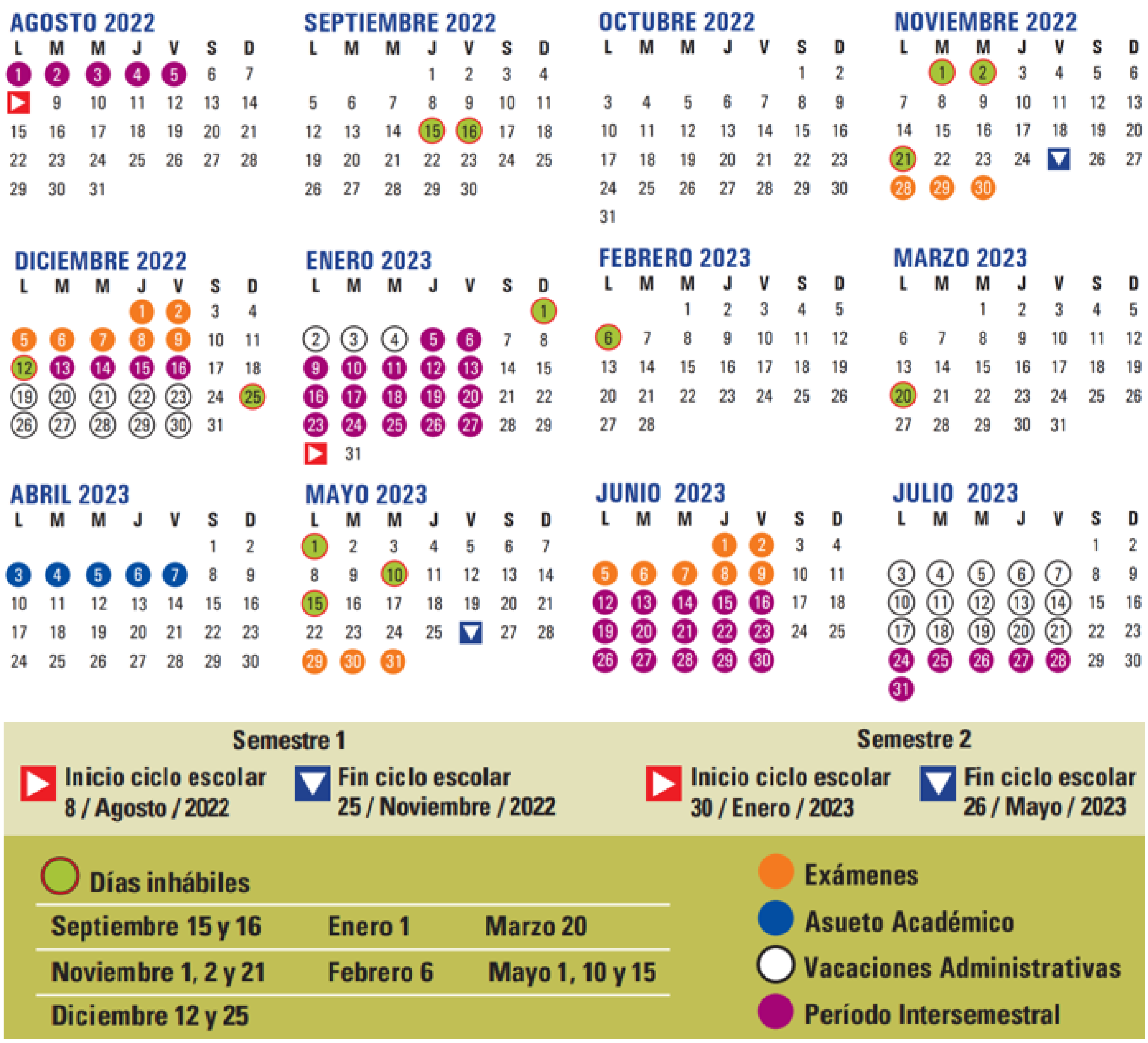


Figure 3.2: School calendar, 2013 semester plan. Source: [UNAM, 2022].

It is assumed that on weekends and holiday periods there is no occupation in any of the new building's spaces, so there is no consumption by equipment, except for those that work all the time and the lights that remain on for security. The annual schedule with which the numerical model is created does not consider any non-working days (dates with green circles in the Figure 3.2), since every year their dates change and it is possible that some occur on weekends, in addition to the fact that if they are not considered, the numerical model is simplified.

The only holiday periods that are considered in the schedules of the numerical model are Easter week, summer break and winter break. The dates of Easter week may vary, but in this case study it is assumed that it begins on March 26 and ends on April 1. The dates of winter and summer breaks are different for the student section and the administrative section. It is assumed that the winter break for students begins on December 10 and ends on January 28, while for the administrative section it begins on December 17 and ends on January 7. The summer break for the student section begins on June 11 and ends on August 5, while for the administrative section it begins on July 2 and ends on July 22.

It is assumed that the four classrooms where students spend their free hours are F1Cr411, F1Cr412, F1Cr413 and F1Cr414 and it is also assumed that those classrooms are at 50% occupancy during free hours, which means an occupancy of 20 people. In the case of the administrative section and the kitchen, it is assumed that occupancy in the spaces remains constant within working hours. In an bachelor class, there is usually only one teacher. Therefore, as there are 4 bachelor groups, a maximum occupancy of 4 teachers can be assumed in the new building. When the teachers finish their classes, it is assumed that they leave the building and are replaced by others who can give the class in the same or another classroom. That is why it is considered that there are always at least 4 teachers in the entire building.

In terms of occupancy, it is assumed that in the new building there is a daily occupancy of 176 people, among which 4 are teachers (who teach classes at the same time), 8 are from the administrative section and 4 are from the kitchen. There are four bachelor groups with 40 people each, so students occupancy is 160. According to the survey carried out, 50% of students remain at the institute to continue working after their last class ends at 6 pm. Therefore, after that time, the number of students in the institute is 80. It is assumed that these 80 people are distributed equally in the two work rooms to occupy them from 6 pm to 8 pm.

3.1.2 Energy loads in the building

To calculate the NZEB balances it is necessary to obtain the annual energy consumption of the new building, which is mainly composed of lighting, electrical equipment and gas equipment loads. Therefore, the information for adding these loads into the numerical model is shown in this subsection, as well as the assumptions made. It is necessary to clarify that only those loads that represent an energy consumption for the building are taken into consideration to calculate the NZEB balances. Therefore, energy consumption by equipments such as laptops or cell phones will only be taken into account if they are connected to the building's electrical grid, the same applies to the rest of the electrical and lighting equipment.

Electrical equipment

To incorporate the electrical equipment loads into the numerical model, it is important to obtain information about the electrical equipment present in each space, including the amount per space, the connection time, and the connection schedule of the equipment. Connection time refers to the time that equipment in a space remains connected to the building's electrical grid during a period. In this work, a methodology was developed to estimate this information by day of the week, for those electrical equipment for which simple assumptions could not be made due to the characteristics of the space type in which they are located and their specific use. Once this dataset has been compiled and integrated into the numerical model, we can then calculate the annual electrical consumption attributed to the building's equipment. Tables 3.6 and 3.7 show the equipment in each space type, as well as their average powers, the amount per space, the connection time and the connection schedule.

Table 3.6: Electrical equipment for each space in the building, part A.

Space type	**Equipment**	**Power (W)**	**Amount per space**	**Connection time**	**Connection schedule**
Classroom	Computer	50	Tables A.44 to A.48	Tables A.44 to A.48	Tables A.44 to A.48
	Cell phone	20	Tables A.49 to A.53	Tables A.49 to A.53	Tables A.49 to A.53
	Projector	300	1	Tables A.54 to A.58	Tables A.54 to A.58
	TV	100	1	Tables A.59 to A.63	Tables A.59 to A.63
Work room	Computer	50	Tables A.44 to A.48	Tables A.44 to A.48	Tables A.44 to A.48
	Cell phone	20	Tables A.49 to A.53	Tables A.49 to A.53	Tables A.49 to A.53
Office	Desktop computer	100	Equal to occupancy	Occupancy hours in Table 3.5	Occupancy schedule in Table 3.5
	Cell phone	20	Equal to occupancy	2 hours	1 pm to 3 pm
	Phone	5	Equal to occupancy	1 hours	9 am to 10 am
	Printer	400	1	2 hours	11 am to 1 pm
	Coffee maker	1000	1	1 hours	9 am to 10 am
3D printing room	Desktop computer	100	1	Occupancy hours in Table 3.5	Occupancy schedule in Table 3.5
	Cell phone	20	1	2 hours	1 pm to 3 pm
	3D printer	500	2	6 hours	10 am to 4 pm
	Cutting machine	50	2	2 hours	4 pm to 6 pm
Computer room	Desktop computer	100	20	Occupancy hours in Table 3.4	Occupancy schedule in Table 3.4
	Cell phone	20	Tables A.49 to A.53	Tables A.49 to A.53	Tables A.49 to A.53
Meeting room	Computer	50	4	Occupancy hours in Table 3.5	Occupancy schedule in Table 3.5
	Cell phone	20	2	Occupancy hours in Table 3.5	Occupancy schedule in Table 3.5
	Projector	300	1	2 hours	12 pm 2 pm

Table 3.7: Electrical equipment for each space in the building, part B.

Space type	Equipment	Power (W)	Amount per space	Connection time	Connection schedule
Teacher's lounge	Computer	50	Equal to occupancy	Occupancy hours in Table 3.5	Occupancy schedule in Table 3.5
	Cell phone	20	2	Occupancy hours in Table 3.5	Occupancy schedule in Table 3.5
	Projector	300	1	2 hours	12 pm 2 pm
	Coffee maker	1000	1	1 hours	9 am - 10 am
Laboratory	Computer	50	Tables A.44 to A.48	Tables A.44 to A.48	Tables A.44 to A.48
	Cell phone	20	Tables A.49 to A.53	Tables A.49 to A.53	Tables A.49 to A.53
	Exhaust fans	60	3	Tables A.64 to A.68	Tables A.64 to A.68
	Laboratory equipment	2000	1	Tables A.69 to A.73	Tables A.69 to A.73
Cafeteria	Microwave	1000	1	2 hours	9 am to 10 am and 1 pm to 2 pm
Kitchen	Double refrigerator	750	1	24 hours	Always on
	Normal refrigerator	150	1	24 hours	Always on
	Freezer	750	2	24 hours	Always on
	Cell phone	20	4	2 hours	11 am to 1 pm
	Coffee maker	1000	1	2 hours	9 am to 10 am and 1 pm to 2 pm
	Blender	400	2	2 hours	9 am to 10 am and 1 pm to 2 pm
	Microwave	1000	1	2 hours	9 am to 10 am and 1 pm to 2 pm
	Cash register	10	2	Occupancy hours in Table 3.5	Occupancy schedule in Table 3.5
Computer service room	Switches	5	148	24 hours	Always on
	UPS	450	1	24 hours	Always on
	Air conditioning	2195.82 (COP = 3.44)	1	24 hours	Always on
Mechanical room	Hydro-pneumatic pump	750	2	24 hours	10 am to 4 pm
	Evaporative system pump	5500	2	24 hours	1 pm to 2 pm

The hydro-pneumatic pump located in the machine room is responsible for supplying water to the kitchen and bathrooms of the building. As the computer room has a maximum capacity of 21 people (where one is the teacher), it is assumed that while this space is being used, 20 computers are connected and being used by 20 students.

The amount of equipment per space, the connection time and the connection schedule of a equipment can vary greatly depending on the space type where it is located and the use given to the equipment, that is, whether it is personal or communal. For example, in both a classroom and an office there are computers and cell phones, however, since the office has less occupancy, it is easier to assume an amount of connected equipment. Unlike classrooms, offices have a fixed work schedule every day, so it is also easier to assume connection times and connection schedules.

On the other hand, in the same space type, such as a classroom, you can find equipment for personal use, such as computers and cell phones, and equipment for communal use, such as projectors and TVs. Assuming an amount of connected projectors and TVs is easier because there is usually only one unit per space. In the case of computers and cell phones, normally each student has their own equipment, so assuming an amount of connected equipment is complicated. Additionally, the schedule for all classrooms changes every day, so making assumptions about connection time and connection schedules is also complicated.

It is important to remember that all the tables that are mentioned within Tables 3.6 and 3.7 only have additional information to add the electrical equipment to the numerical model, so if you want to know in more detail the methodology that was used to calculate that information, it is necessary to read all the annexes chapter.

Gas equipment

It is assumed that the only places where gas equipment is installed are the laboratories and the kitchen. The Table 3.8 shows the equipment in each space type, as well as their average powers, the amount per space, the connection time and the connection schedule.

Table 3.8: LP gas equipment for the laboratory and the kitchen.

Space	Equipment	Power (W)	Amount per space	Connection time	Connection schedule
Laboratory	LP gas unit	67	1	30 minutes	Occupancy schedule in Table 3.4.
Kitchen	LP gas unit	37	1	9 hours	8 am - 5 pm

These equipment only work with LP gas, which has a calorific value and density of 97.26 MJ/m^3 and 540 kg/m3 [Secretaría de Gobernación, 1986], respectively. To obtain the power of the LP gas equipment of the laboratories and the kitchen (using the equation 2.5), it is still necessary to collect information about the LP gas consumption per year (kg) and the LP gas hours of use per year (h), for each of the spaces. The data in the Table 3.9 were provided by those in charge of the laboratories and the kitchen of the IER building, since they are the only spaces that can be used as a reference to size the gas equipment.

Table 3.9: Information of the LP gas equipment in the building.

Space type	Operation days (-)	Operation months (-)	LP Gas consumption per month (kg)	LP gas consumption per year (kg)	LP gas hours of use per day (h)	LP Gas hours of use per year (h)	Power (W)
Laboratory	223	7	80	560	2	446	67
F0Kit	247	8	200	1647	9	2223	37

In the first column, the days of operation are the days that those space types operate throughout the year. This information takes into account the assumptions made for the bachelor schedule of this study case. If those days are transformed into months, the second column is obtained. The third column shows the LP gas consumption of each space type. This information was obtained from the people in charge of the laboratories and kitchen. If the consumption per month is multiplied by the months of operation, the result is consumption per year, seventh column. The sixth column shows the daily hours of LP gas use. It is assumed that in a day all laboratories use LP gas equipment for 2 hours. While in the kitchen the equipment is used the 9 hours of occupation. If the daily hours of use are multiplied by the days of operation, the annual hours of use are obtained, eighth column.

The last column of the Table 3.9 shows the power of the gas equipment for each of the spaces. According to the bachelor schedule, students take twenty hours of laboratory classes in a week. It is also shown that none of these classes are taken on Mondays. Therefore, if it is considered that on each day where there are laboratory classes, the LP gas equipment in the laboratories is used for a total of two hours, this means that the equipment is used for a total of 8 hours during the week. If these are divided among the 20 hours of laboratory classes that there are per week, results that in each laboratory class the LP gas equipment should be turned on for around 24 minutes, an amount that is rounded to 30 minutes for simplicity. Therefore, to achieve the 8 hours a week of LP gas equipment working, it will be considered that for every hour that there are laboratory classes, 30 minutes an LP gas equipment is working. In the case of the kitchen, it is assumed that the LP gas equipment is working while there is occupation in the kitchen.

Lights

One of the final uses that makes the greatest contribution to the energy consumption of buildings is lighting. To obtain the amount and power of the lighting equipments in the spaces, electrical load plans of the new IER building were used. The plans were provided by the group of architects who designed the new building. The Table 3.10 shows the quantity, power, total power, and week schedules of the lighting equipment that is installed in each space of the building. It is assumed that the interior spaces of the building are not used on weekends, so no lighting equipment is used.

Table 3.10: Information of lights equipment in the building.

Space type	Space	Power per light (W)	Amount (-)	Week schedules	Weekend schedules
Classroom	F1Cr401	25	12	8 am - 9 am 5 pm - 7 pm	Not used
	F1Cr402	25	12		
	F1Cr403	25	12		
	F1Cr404	25	12		
	F2Cr101	25	6		
	F2Cr102	25	6		
	F2Cr103	25	6		
	F2Cr201	25	6		
	F2Cr202	25	6		
	F2Cr203	25	6		
Office	F0AdmOff	25	5	9 am - 10 am 5 pm - 7 pm	Not used
	F0AdmOff	36	3		
	F0Coor	25	4		
	F03DPrint	36	4		
	F0Comp	36	12		
	F0Meet	25	2		
	F0Teach	36	4		
	F0Lobby	36	1		
Office	F0AttCOFI	36	2	9 am - 7 pm	Not used
	F0AttCOFI	7	1		
	F0CoorCOFI	36	1		
Laboratory	F1Lab	25	24	4 pm - 6 pm	Not used
	F2Lab1	25	9		
	F2Lab2	25	9		
Restroom	Restroom Ground floor	36	4	6 pm - 7 pm	Not used
	Restroom 1st floor	36	4		
	Restroom 2nd floor	36	4		
Work room	F0Work	25	18	6 pm - 8 pm	Not used
	F2Work	25	14		
Parking lot	Parking lot	12.5	40	6 am - 10 am 6 pm - 10 pm	6 am - 10 am 6 pm - 10 pm
Corridor	F2Corr	25	6	6 pm - 10 pm	Not used
Cafeteria	F0Cafe	25	20	Not used	Not used
Kitchen	F0Kit	25	9	8 am - 6 pm	Not used
Computer service room	Computer service room	12.5	4	1 pm - 2 pm	Not used
Mechanical room	Mechanical room	12.5	14	8 am - 12 pm	8 am - 12 pm
Rooftop	Rooftop	25	9	5 pm - 8 pm	Not used

The week schedules in which the lights are on in the classrooms and offices were determined with the help of the work of Betancourt [2020]. In her work, she calculates the useful daylight illuminance (UDI) for classrooms and office areas. The UDI is defined as the percentage of annual hours in which the illuminance at a point in the evaluated space falls within a certain range.

In her work, she defines a lower and an upper limit to classify illuminance values into three categories. For both classrooms and offices, 300 lx and 2000 lx were selected as the lower limit and upper limit, respectively. The lower limit was defined based on NOM-025-STPS-2008, which establishes the required illuminance as 300 lx in spaces where office activities are carried out [Diario Oficial, 2008], while the upper limit is the one proposed in [Nabil and Mardaljevic, 2006], a from which both visual and thermal discomfort may be experienced. On the other hand, the UDI calculation requires defining a working schedule during which the contribution of natural lighting to the space will be analysed. Her work assumes a working schedule of 8 am to 6 pm for classrooms and offices. This work assumes a working schedule of 8 am to 6 pm for classrooms and 9 am to 7 pm for offices. Since schedules of Betancourt [2020] are very similar to those of this work, it is assumed that the same UDI applies to all the schedules. Figure 3.3 shows the office area from which the UDI will be obtained.

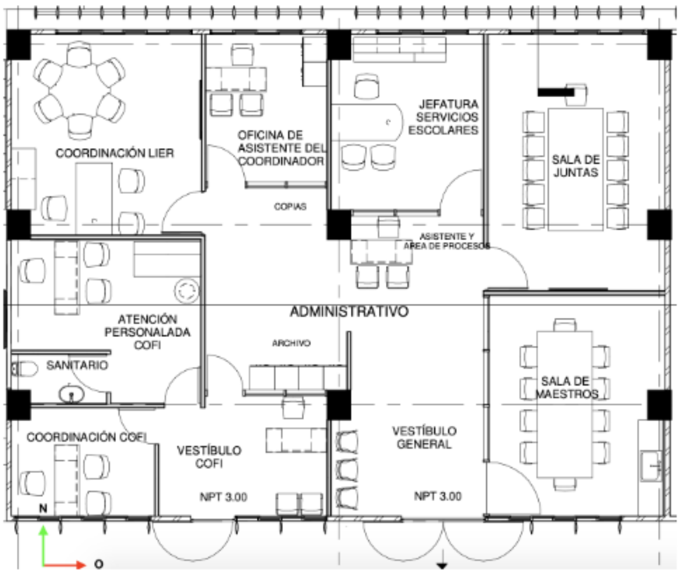


Figure 3.3: Architectural plan of the office area..

The Figure 3.4 shows a UDI map of the office area, where UDI_{und} represents the percentage of working hours during which the illuminance at each point is below 300 lx, UDI_u represents the percentage of hours during which the illuminance is between 300 lx and 2000 lx and UDI_{over} shows the percentage of hours during which the illuminance exceeded 2000 lx.

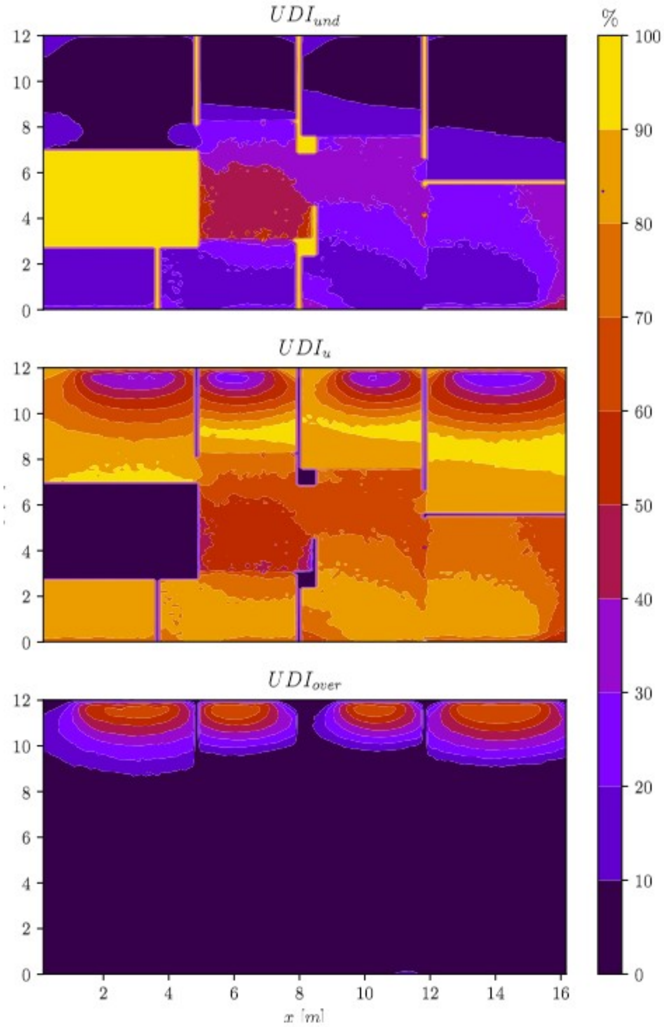


Figure 3.4: Useful daylight illuminance map of the office area.

For this work, it is required to know how many hours of the day the offices are sub-lighted, since it is assumed that these are the hours that the lights should be turned on. In the UDI_{und} at the top of the map, it is possible to observe that that the COFI suppor office (in spanish Atención personalizada COFI) is underlit 100% of the time. On the other hand, for reasons of simplicity it is assumed that the rest of the offices have sub-lighting conditions for 30% of working hours. This value was chosen because it is the most predominant in the area.

Therefore, if the working hours of the COFI support office is from 9 am to 7 pm and 100% of these hours are in sub-lighting conditions, then the lights must be on during all working hours. In this work, for reasons of simplicity, it is assumed that all COFI offices have their lights on working hours. The rest of the offices have working hours from 9 pm to 7 pm and 30% of these hours are in sub-lighting conditions. If the work schedule consists of 10 hours, then 3 of those have sub-lighting conditions. These 3 hours were distributed one in the morning (9 am to 10 am) and two in the afternoon (5 pm to 7 pm), as seen in the Table 3.10. A similar methodology was applied in the classrooms to determine the time the lights remain on.

To account for the total lighting consumption of a building, it is necessary to consider exterior lights, which are turned on when daylight is low in outdoor spaces. For this reason, the Table 3.11 shows the amount, power, total power, week schedules and weekend schedules of the lighting equipment that is installed in the outdoor spaces of the new IER building. Again, all the information on this equipment was obtained from an electrical plan that was provided by the institutes's coordination. All these spaces must remain well lit every day of the year for security reasons, so the lighting equipments installed are supposed to be working every day of the year in the adequate schedule. Finally, it is important to clarify that the week schedules are also repeated on the weekend.

Table 3.11: Exterior lights in the ground floor and the rooftop of the building.

Space	Amount (-)	Power (W)	Total power (W)	Week schedules
Exterior	15	37	555	6 pm - 8 am
	4	38	152	6 pm - 8 am
	4	25	100	6 pm - 8 am
	20	38	760	6 pm - 8 am
	7	8	56	6 pm - 8 am
	15	10	150	6 pm - 8 am
	15	10	150	6 pm - 8 am
	8	150	1200	6 pm - 8 am

3.1.3 Electricity rate for the new IER building

To calculate cost-NZEB, it is essential to understand the electricity rate assigned to the new IER building. The institute inaugurated its facilities in 2013, a period in which it was subject to the Hourly Rate in Medium Voltage (H-M for its acronym in Spanish). However, in 2017, the electricity company (CFE) carried out a restructuring that involved changes in the nomenclature and the inclusion of new elements in some rates. As a result of this process, the IER is currently subject to the Large Demand Medium Voltage Hourly rate (GDMTH for its acronym in Spanish). The main characteristics of these two rates are detailed below.

H-M Electricity Tariff

This rate applies to services that supply energy for any purpose at medium voltage, with a demand of 100 kW or higher. The charges encompass:

- Energy: Comprising peak, intermediate, and base energy, each reflecting consumption during periods with varying kilowatt-hour (kWh) prices. Peak energy carries the highest cost and is subject to seasonal variations such as summer and winter, as well as regional factors.
- Billable Demand (BD): A function involving maximum demands across the three time periods, calculated monthly based on the highest consumption of electrical energy recorded within 15-minute intervals, measured in kilowatts (kW) [CFE, 2022]. Equation 3.1 illustrates the calculation of DF.

$$BD = PD + IRF \times max(ID - PD, 0) + RBF \times max(BD - PID, 0) \tag{3.1}$$

  Where,

  - PD: Maximum demand during peak hours (PH)
  - ID: Maximum demand in intermediate hours (IH)
  - BD: Maximum demand in base hours (BH)
  - PID: Maximum demand in peak and intermediate hours
  - IRF and RBF: Reduction factors contingent upon the user's tariff region.
- Power Factor (PF): An indicator of energy utilization ranging between 0 and 1, with 1 being ideal. A PF below 0.90 indicates wastage, incurring penalties. Conversely, a PF of 0.90 or above results in no charges, with bonuses for exceeding this value ([Gobierno de México and CONUEE, 2016]).

GDMTH Electricity Tariff

This rate, replacing the H-M, serves the same services but incorporates energy charges across three periods: base, intermediate, and peak, along with those related to PF. To determine the demand charge, Capacity and Distribution concepts are introduced. Equations 3.2 and 3.3 elucidate their computation.

$$Capacity = min(Dmax_{peak}, \frac{Q_{monthly}}{24 \times FC \times d}) \tag{3.2}$$

Where,

- $Dmax_{peak}$: Maximum demand during peak hourly period, measured in kW.
- $Q_{monthly}$: Monthly consumption recorded in kWh for the billing month.
- d: Number of days in the billing period.

$$Distribution = min(Dmax_{monthly}, \frac{Q_{monthly}}{24 \times CF \times d}) \tag{3.3}$$

Where,

- $Dmax_{monthly}$: Maximum demand recorded for the month.
- CF: Charge factor, defined as the ratio of average demand to maximum demand within the same analysis period (equation 3.4).

$$CF = \frac{Dprom}{Dmax} \tag{3.4}$$

The value of CF is fixed and specific to each rate.

3.2 Creation of the numerical model

The construction of the numerical model can be divided into two important steps: the creation of the geometry of the new building and the addition of energy loads in the energy simulation software. The Energy in Buildings group of the IER created the geometry of the building in SketchUp, while the addition of energy loads in EnergyPlus was carried out as part of this thesis project. Regarding the geometry, the dimensions of each space were obtained from the building plans provided by the IER coordination. Because of the high simulation time that it would cost to build a numerical model with all the spaces and loads that the new building has, it was decided to divide the new building into an east and a west section and for each of these a geometry was built in SketchUp, which can be seen in Figures 3.5 and 3.6.

Figure 3.5: South view of the East Section's geometry.

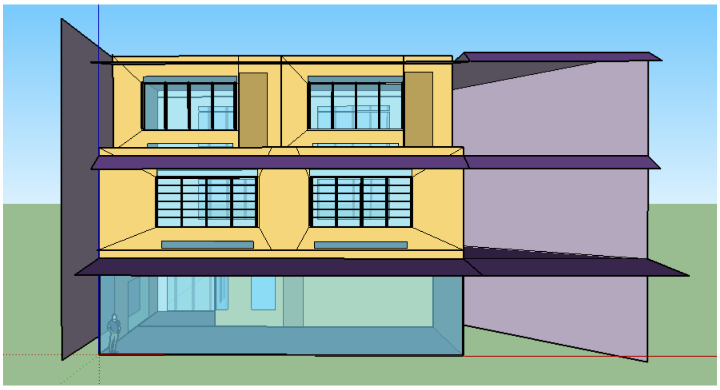


Figure 3.6: South view of the West Section's geometry.

The yellow surfaces represent the walls of the spaces, the purple ones represent the shadings surfaces and the transparent blue ones represent the windows. To reduce the simulation time and to simplify the design of the geometry in SketchUp, it was decided to only create the spaces that were on the ground floor, first floor and second floor. The only exception to this are the restrooms, which were also not drawn in SketchUp since their energy contribution is much lower compared to the other spaces and including them would increase the simulation time. Spaces such as restrooms, machine room, computer service room, parking lot, roof, and outdoor spaces were not included in SketchUp geometry, but their energy contribution is calculated separately.

Once the geometry is finished, the data is sent to the energy simulation programme, where characteristics are assigned to the numerical model, such as materials and construction systems, the occupancy in the spaces, loads, schedules, output variables and the time step. For this simulation, it was chosen that there are 6 time steps per hour, so in the data series, values will be shown every 10 minutes.

3.3 Results of the numerical model

Once the numerical model of the new building was completed, annual information on the following variables can be obtained:

- Electrical consumption by equipment = 43 MW
- Electricity consumption by lights = 20.4 MWh
- Total electricity consumption = 63.4 MWh
- LP gas consumption = 0.1 MWh
- Total energy consumption = 63.5 MWh
- Energy Use Intensity (EUI) = 31.8 kWh/m^2

It is important to remember that the EUI is calculated by dividing the total energy of the building by the total gross floor area, which is 1,993.6 m^2. On the other hand, the electricity consumption by equipment refers to the electrical energy consumed by all those equipment that are not used for lighting, while total electricity consumption refers to the sum of electricity consumption by equipment and electricity consumption by lights.

As mentioned in the first chapter, the measures used to compare the energy performance of a building and check how close it is to reality are electrical power density and EUI. The LPD and EPD values obtained from the study case are compared with the values calculated by ASHRAE [2022] ,for LPD values, and those of [Mahajan et al., 2017], for EPD values. However, it is necessary to remember that the power densities can only be compared when the values are calculated with the same method (these can be consulted in Section 1.6.1). Since ASHRAE [2022] calculates its LPD values with the method based on lighting requirement, this must be used to calculate the LPD values for the study case. On the other hand, to calculate their EPD values, Mahajan et al. [2017] use the method based on consumption, so the EPD values of the study case must be calculated with the same method. The Table 3.12 shows the total power (TP_{sc}), the annual electricity consumption (AEC_{sc}) and the total area (TA_{sc}) with which the LPD and EPD values of the study case are calculated.

Table 3.12: LPD and EPD values obtained from the study case, by space type.

	Lighting			Equipment	
Space type	TP_{sc} **[W]**	TA_{sc} $[m^2]$	**LPD** $[W/m^2]$	AEC_{sc} **[kWh/per year]**	**EPD** $[W/m^2]$
Classroom	2100	572.80	3.66	4615.2	0.92
Office	786	204.93	3.83	3375	2.04
Computer classroom	432	75.54	5.71	871.20	1.32
Kitchen	225	63.41	3.54	7848.52	14.13
Corridor	100	51.85	1.92	0	0
Lobby	36	12.50	2.88	393.75	3.60
Laboratory	1050	364.34	2.88	4538.52	1.36
Work room	800	188	4.25	424.80	0.26
Computer service	50	16	3.12	16013.28	114.25
Cafeteria	500	137.63	3.63	450	0.37
Restroom	432	54	8	0	0
Mechanical room	175	252	0.69	4500	2.04
Parking lot	500	2475	0.20	0	0
Rooftop	225	575	0.39	0	0
Exterior	3123	2745	1.13	0	0

In the case of lighting equipment, the building plans already have information about the power installed in each space. So, to find the LPD values for each type of space, we added up the powers of all the spaces of that type and divided it by the total floor area of those spaces.

Table 3.13 compares the LPD values calculated in this work with those obtained by ASHRAE [2022], while Table 3.14 compares the EPD values obtained in this work with those of ASHRAE [2009] and Mahajan et al. [2017].

Table 3.13: Comparison between the LPD values obtained in this work and those from other sources, by space type.

	LPD [W/m^2]		
Space type	**Maciel (2023)**	**Prescriptive pathway - ASHRAE (2022)**	**Performance pathway - ASHRAE (2022)**
Classroom	3.66	7.75	15.65
Office	3.83	6.03	11.84
Computer classroom	5.71	8.07	23.03
Kitchen	3.54	12.80	12.91
Corridor	1.92	4.73	5.38
Lobby	2.88	8.61	14
Laboratory	2.88	13.02	15.06
Study room	4.25	7.75	15.65
Computer service	3.12	7.85	16.14
Cafeteria	3.63	3.87	9.68
Restroom	8	7.96	9.68
Mechanical room	0.69	7.64	16.14
Parking lot	0.20	0.40	18.83
Rooftop	0.39	0.75	2.15
Exterior	1.13	0.75	2.15

Table 3.14: Comparison between the EPD values obtained in this work and those from other sources, by space type.

	EPD [W/m^2]		
Space type	**Maciel (2023)**	**ASHRAE (2009)**	**Mahajan (2016)**
Classroom	0.92	10.8	2.152
Office	2.04	10.8	4.304
Computer classroom	1.32	10.8	2.690
Kitchen	14.13	10.8	15.064
Corridor	0	10.8	1.076
Lobby	3.6	10.8	0.215
Laboratory	1.36	10.8	2.690
Study room	0.26	10.8	2.152
Computer service	114.25	10.8	15.064
Cafeteria	0.37	10.8	-
Restroom	0	10.8	-
Mechanical room	2.04	10.8	-
Parking lot	0	0	0
Rooftop	0	0	0
Exterior	0	0	0

In the first chapter it is explained that ASHRAE documents have compliance paths, which include requirements that building makers must take into account when designing buildings, so that they can comply with the energy codes of the country or of ASHRAE itself. Two of its main compliance paths are the prescriptive method and the performance rating method, whose characteristics are described in the first chapter. In summary, the prescriptive method is more restrictive (it has smaller values) than the performance rating method. The LPD values calculated in this work are even smaller than those of the prescriptive method, which is attributed to the energy efficiency measures in the lighting equipment of the new building and the bioclimatic design that seeks a better use of daylight.

According to the Table 3.14, the EPD values can be compared with data from two other sources. However, the only value that ASHRAE [2022] proposes is 10.8 W/m^2, which was calculated with the common method and corresponds to an office building, so it would not be appropriate to use it to compare the EPD obtained from this work. For this, Mahajan et al. [2017] values are used, which were calculated with the method based on consumption in an academic building and the values are presented by type of space. However, they does not have information for all of the space types in this study case, so the EPD values for those spaces are compared to the ASHRAE [2009] default value.

In almost all the spaces, the EPD values of this work are lower than those calculated by Mahajan et al. [2017], which is because of, in their study, they monitored some of the equipment in the spaces and recorded information about the time that they remained in the four modes of use: active, idle, sleep and off. Therefore, with the power, they were able to calculate the energy consumed by the equipment in each mode of use, while in this work the equipment could not be monitored for resource availability, so only the consumption in active mode is considered. The fact of considering the consumption in all modes of use of an equipment, the amount of equipment per space and the hours of use, is the reason why the EPD values of Mahajan et al. [2017] are higher than those calculated in this work.

The lobby and the computer service room are the spaces that do not follow this trend. In the lobby, that behaviour is because this study considers that there is much more energy consumption by equipment than in the lobby of Mahajan et al. [2017], where they only assume that laptops are used sometimes. On the other hand, the computer service room has a much higher EPD than Mahajan et al. [2017], which is because the equipment considered in both studies is not the same. While in this studio, the computer service room has equipment like switches, UPS unit, and air conditioner (which are active all the time), the analogue space has computers, projectors, printers, copiers, and others. The amount and hours of these equipment make it one of the spaces with the highest power density in that study, however, it is far from similar to the consumption of the computer service room in this study, which also explains the enormous difference between their EPD values.

For this study case, a gross floor area of 1993.6 m^2 is assumed to calculate the EUI of the new building. The new IER building is located in Morelos, which, according to the classification of Kerdan et al. [2015], has a temperate climate, so the building must have an EUI close to 62 kWh/m^2 per year.

For the calculation of the EUI in this work, the electrical contribution by equipment and lighting equipment located in spaces outside the total gross floor area is considered (spaces such as the rooftop, parking lot and outdoor spaces). The Figure 3.7 shows the comparison between the EUI obtained from Kerdan et al. [2015] and that calculated in this work. The EUIs of both works are shown on their LP gas, lighting and electrical equipment components.

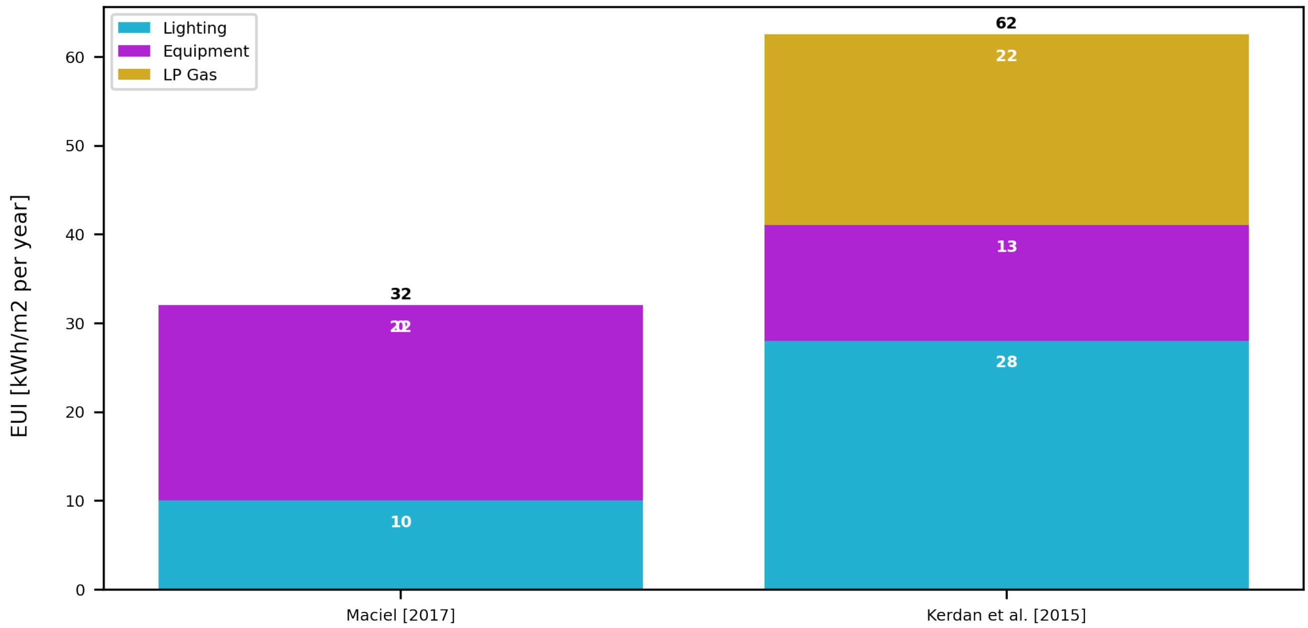


Figure 3.7: Comparison between the EUI values obtained by Kerdan et al. [2015] and the ones obtained by Maciel [2023].

In general terms, the EUI of this work exceeds the value obtained by Kerdan et al. [2015] by 30.5 kWh/m^2 EUI units. The main reason for this difference is because the EUI of Kerdan et al. [2015] includes 21.5 kWh$/m^2$ per year for gas use. The academic building model that they used to obtain this value has an area of 7,500 m^2, which means that the building has an annual gas consumption of 161,250 kWh per year, which is considered a very high value for an academic building. This is explained if one considers that Kerdan et al. [2015], unlike this work, use domestic hot water for bathrooms and this represents 6 kWh/m2 EUI units of the 21.5 kWh/m2 EUI units for gas use. In addition, their work considers more spaces that use LP gas for cooking, unlike this work where there is only one kitchen of 63.41 m2.

In terms of the equipment, the difference is caused by the inclusion in this work of the computer service room, which has devices such as switches, a UPS unit (Uninterruptable Power Supply) and air conditioning. This space requires that these three elements always remain in operation, which causes this space to consume much more energy than the rest. The building total energy consumption by equipment is around 43 MWh per year, while the consumption for this space alone is 16 MWh. This means that the computer service room is responsible for almost one third of the annual equipment consumption. Although Kerdan et al. [2015] do not specify the equipment with which the equipment EUI value was calculated in the Table 1.8, it is assumed that they refer only to the use of computers and other miscellaneous equipment (printers, projectors, telephones, coffee makers and others).

In terms of lighting, the difference is because of the lighting EUI value that they calculated is almost three times higher than that obtained in this work. The new IER building had a bioclimatic design that allows taking advantage of natural lighting in the spaces, so that lighting equipment does not have to be turned on until later and energy is saved. On the other hand, efficient lighting equipment was installed in the building, so that, even if artificial lighting is used, a lower amount of energy is consumed. These elements with which the new building was built make that its annual lighting consumption is much lower than in other buildings with the same type of use.

Chapter 4

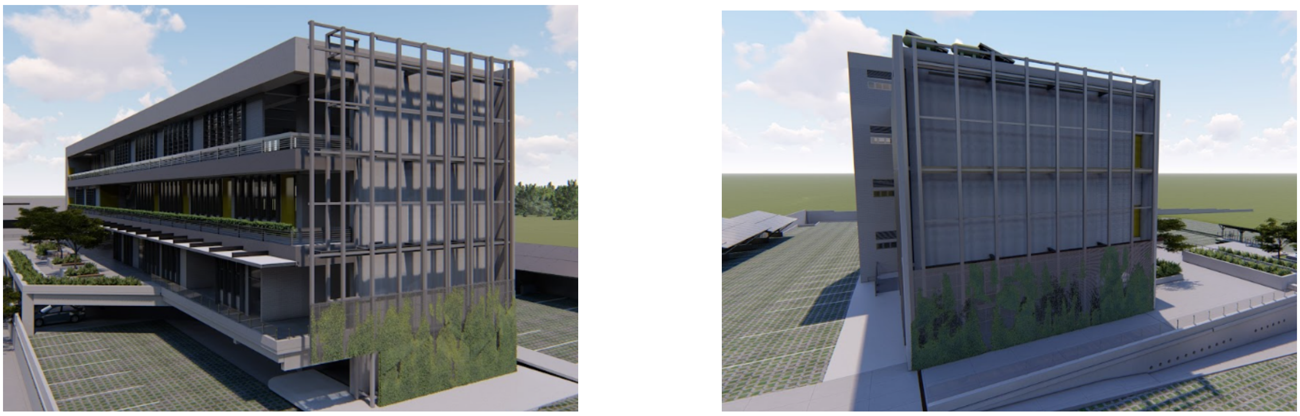
Scenarios and evaluation of the NZEB definitions

Compliance with NZEB definitions is greatly affected by annual energy consumption and annual renewable energy generation. Therefore, in this chapter, scenarios are created based on combinations that can be made with two renewable energy generation options in the new building and three consumption options: the base case consumption, presented in the previous chapter, the consumption with LPD values and the consumption with EPD values. In each of these scenarios, compliance with the four NZEB definitions is evaluated. With the results of the study case shown in the previous chapter, a base case (BC) is created, which serves as a starting point for applying all generation and consumption options. Section 4.1 describes the characteristics of the renewable generation options that will be used to create the scenarios, while Section 4.2 does the same for the consumption options. Finally, section 4.3 describes the created scenarios and shows the results of the evaluation of the NZEB definitions in each of them, as well as their respective analysis.

4.1 Renewable generation options

Below is a brief description of the two renewable generation options in the building, as well as the method that a simulation should use to calculate the renewable energy generated. On the other hand, there is no information on when or in what order the systems will be placed, so scenarios are created that present all possible situations.

- **East and West façade:** In front of the east and west façades there is a vertical metallic structure of 205 m^2 each. Those structures are considered to install photovoltaic modules, which, in addition to generate renewable electricity for the building, also work as solar protection for the east and west façades, as can be seen in Figure 4.1 .



(a) East façade

(b) West façade

Figure 4.1: Metallic structure in the building façades.

- **Parking lot:** In the North parking lot of the new building there is an available area of 234 m^2 where it is planned to install a photovoltaic system. The installed surface of photovoltaic modules is also considered to provide shade for parked cars, so it will be suspended 2.25 m from the ground and will have an inclination of 18.85^o, corresponding to the latitude of Temixco. The location of the photovoltaic system on the building site is shown at the top of the Figure 4.2.

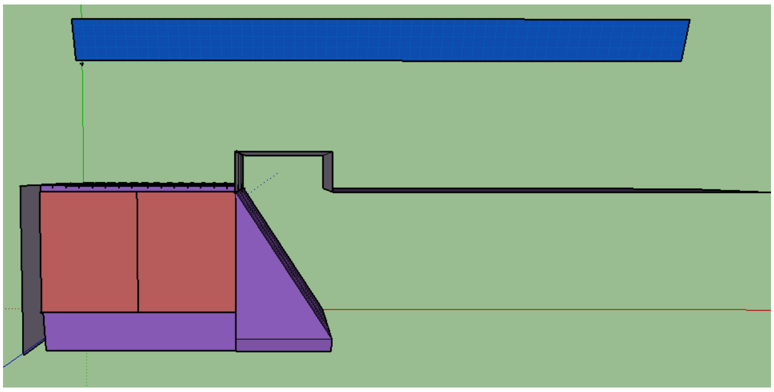


Figure 4.2: Top view of the solar PV arrangement in the North parking lot.

To add renewable generation in a EnergyPlus simulation, the simplest model of photovoltaic generation is used. In this model the user specifies the efficiency with which surfaces convert incident solar radiation to electricity. The full geometric model for solar radiation is used, including sky models, shading, and reflections, to determine the incident solar resource. Power levels are assumed constant over the timestep to arrive at energy production [U.S. Department of Energy, 2022].

This model uses the next expression to calculate the electrical power (P) produced by a PV surface:

$$P = A_{surf} \times f_{activ} \times G_T \times \eta_{cell} \times \eta_{invert}, \tag{4.1}$$

where:

- A_{surf} is the net area of surface of the PV array (m^2),
- f_{activ} is the fraction of surface area with active solar cells ($-$),
- G_T is the total solar radiation incident on PV array (W/m^2),
- η_{cell} is the module conversion efficiency ($-$) and
- η_{invert} is the DC to AC conversion efficiency ($-$).

In the previous equation, G_T is calculated by EnergyPlus and the rest are user inputs. To use this simple model of photovoltaic generation, EnergyPlus requires selecting the surface where the photovoltaic modules will be installed. The Figure 4.1 shows the structures where the photovoltaic systems on the East and West façades are planned to be installed. Each of these structures has an available area of 205 m^2 to install photovoltaic modules, this value corresponds to the A_{surf}. Of this area, only 65% will be used to install the photovoltaic modules in both façades, since the rest is contemplated to make green walls, this value corresponds to the f_{activ}. The efficiencies of the module and the inverter are $\eta_{cell} =$ 0.169 and $\eta_{invert} =$ 0.98, respectively [Renesola, 2023].

In the North parking lot, a photovoltaic array with an area of 234 m^2 is considered, this value corresponds to the A_{surf}. Of this area value, 100% of the surface will be used to install the photovoltaic modules and this value corresponds to the f_{activ}. Again, the efficiencies of the module and the inverter are $\eta_{cell} =$ 0.169 and $\eta_{invert} =$ 0.98, respectively [Renesola, 2023].

Table 4.1 presents the maximum power (P_{max}) and the annual renewable energy generated (GEN_{ren}) for each of the PV systems, as well as for the combination of both.

Table 4.1: Maximum power and annual renewable energy generate for each of the PV systems.

PV system	P_{max}	GEN_{ren}
East and West façades	26.3 kW	52.6 MWh
North parking	48.8 kW	88.5 MWh
Combined	75.1 kW	141.1 MWh

CFE [2022] has three schemes for the interconnection of electrical energy generation systems, such as solar photovoltaic. Below is a brief description of each one:

- Net metering: Under this scheme, the electrical energy that is injected into the grid is accounted for and deducted from the energy that the user consumes from the grid. That is, if in a month a user generates more energy than they consume, that surplus will be counted and used to reduce their bill in the next billing period. It is a kind of energy balance.
- Net billing: In this scheme, the energy injected and the energy consumed are billed separately. The user pays for the energy consumed from the grid and receives a payment (usually at a certain price) for the energy injected.
- Total energy sale: The client sells all generated energy to CFE without a customer supply contract.

According to CFE [2022], if the generation system has a capacity less than or equal to 500 kW, non-residential buildings could qualify for the net metering scheme. In the case of the new IER building, the maximum power that a generation system could have is 65.9 kW, which corresponds to the combination of the PV system of the façades and the northern parking lot. Therefore, it is assumed that the interconnection contract that the new building has is under the net metering scheme.

4.2 Consumption options

To determine the annual energy consumption of the building, EnergyPlus requires information on electrical equipment, lighting, and gas equipment loads. Alternatively, instead of specifying the amount, power, and schedule for each load, a power density can be assigned to each space. The method chosen for calculating power density determines how annual consumption is computed (see methods in Section 1.6.1). If using the method based on consumption, no occupancy schedule is needed; a constant schedule assumes the space's power is utilized for all 8760 hours. However, if employing the common method or the method based on the lighting requirement, an occupancy and use schedule must be added to the space.

Despite the fact that many investigations have been carried out to determine the power densities of equipment, lighting and gas, only those of ASHRAE [2022], for lighting, and those of Mahajan et al. [2017], for equipment, are used to make a comparison with values calculated from this work. The clearest advantage of using these values is that they are presented by space type, which makes easier to assign them to spaces of the new building. The consumption of LP gas is the only one that remains constant in all consumption options and that is because there is no ASHRAE or similar document that provides information about LP gas powe density values. In the case of LPD values, ASHRAE [2022] provides two paths of compliance and the main differences between them is that the prescriptive method has smaller values than the performance rating method, which means that the energy consumption by space is more limited. Therefore, the values of the prescriptive method (Table 3.13) are selected to be added to the numerical model as part of different scenarios.

Below are the three consumption options in the new building that will be used to create the scenarios, as well as their most important characteristics. It is assumed that, on weekends and holiday periods, the building's consumption decreases greatly, since there is no occupancy in any of the spaces in the new building. Therefore, there is no consumption by equipment, except for those that work all the time and the lights that remain on for safety.

It is important to clarify that, in the consumption option that uses LPD values, only the lighting consumption of the base case is replaced by the consumption calculated using LPD values. Consumption for other elements remains the same. Everything mentioned previously applies in the same way for the consumption option that uses EPD values.

4.2.1 Base case consumption

It was obtained by adding the lighting, equipment and LP gas loads in the numerical model, along with their respective schedules of use. The Table 4.2 shows the electrical consumption by equipment (E_{ec}), the electrical consumption by lighting (E_{lc}), the consumption by LP gas (C_{lpg}), the total energy consumption (C_{tot}) and the energy use intensity (EUI) that were obtained from the base case consumption. It is important to clarify that all variables were calculated for an annual period.

Table 4.2: General results of the base case consumption.

Variable	Result
E_{ec}	43 MWh
E_{lc}	20.4 MWh
C_{lpg}	0.1 MWh
C_{tot}	63.5 MWh
EUI	31.8 kWh/m^2

The EUI obtained from the base case consumption is 31.8 kWh/m^2 and the EUI calculated by Kerdan et al. [2015] for a building located in a temperate climate in Mexico is 62 kWh/m^2. As mentioned in the previous chapter, the main reason of this difference is because of the high use of LP gas in the school model and the lighting EUI in the study of Kerdan et al. [2015]. The new IER building's bioclimatic design allows natural lighting, reducing the need for artificial lighting and resulting in significant energy savings. Additionally, energy-efficient lighting equipment further minimizes energy consumption, making the annual lighting consumption much lower compared to similar buildings.

The Figure 4.3 shows the base case consumption profile on a business day.

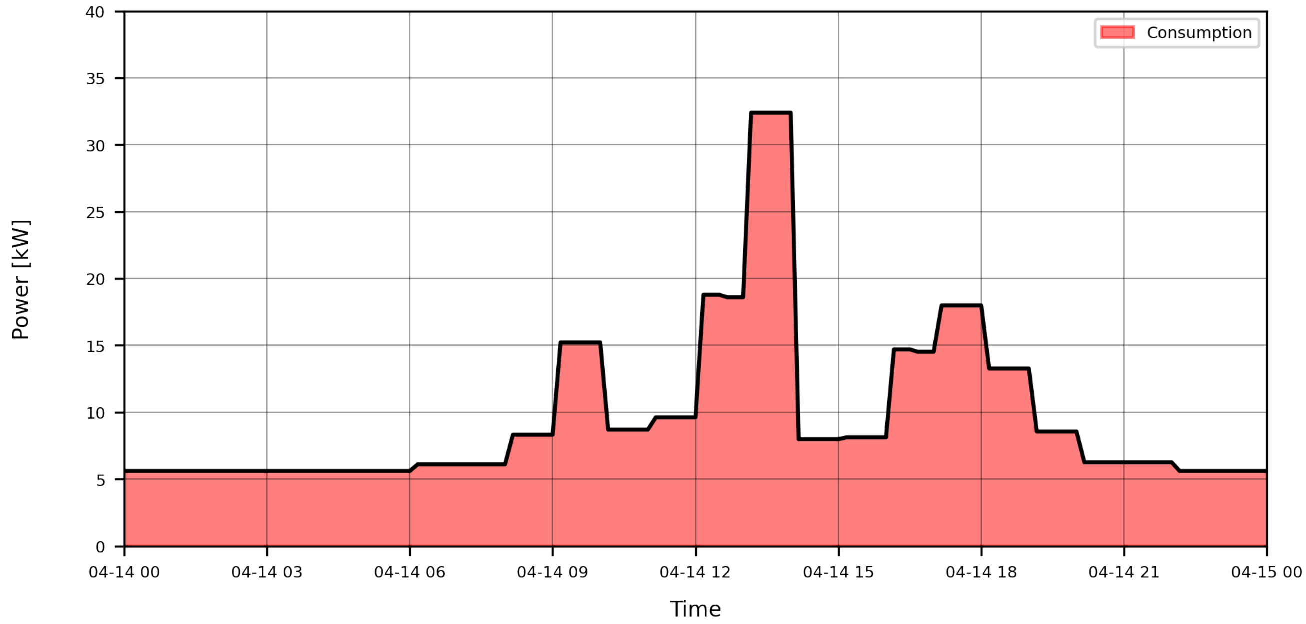


Figure 4.3: Base case consumption profile on a business day.

In an academic building each weekday has a characteristic consumption profile, since different activities take place all days. The profile shown in the Figure 4.3 belongs to a Thursday. Despite the differences that exist in the profiles of each day, they all have the same energy behaviour, which consists of a low consumption between 9 PM and 8 AM (night time) and a medium-high consumption between the remaining hours (occupation hours). The peak power is approximately 33 kW. On every day, the power peak takes different values, but it almost always occurs between 12 PM and 2 PM, which is because of the large number of electrical equipments that are connected in the building, such as computers, cell phones, projectors and others.

4.2.2 Consumption with LPD values

It was obtained by adding the LPD values of ASHRAE [2022] in the numerical model, along with their respective schedules of use. The Table 4.3 shows the general result obtained from the consumption with LPD values. It is important to clarify that all variables were calculated for an annual period.

Table 4.3: General results of the consumption with LPD values.

Variable	Result
E_{ec}	43 MWh
E_{lc}	23.8 MWh
C_{lpg}	0.1 MWh
C_{tot}	66.9 MWh
EUI	33.5 kWh/m^2

Unlike the Table 4.2, in Table 4.3 E_{lc} increases because of the use of the LPD values, so C_{tot} and EUI also increase. The EUI, calculated based on a gross floor area of 1993.6 m^2, is 33.5 kWh/m^2.

The Figure 4.4 shows the consumption profile of the case with added LPD values on a business day.

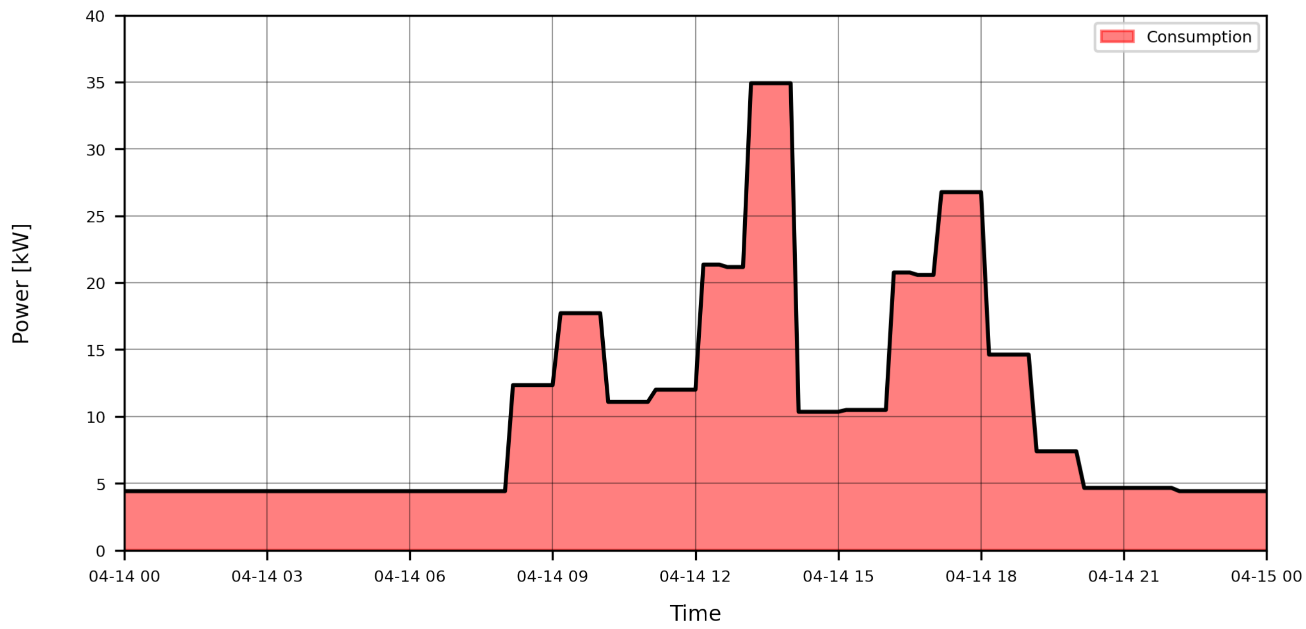


Figure 4.4: Consumption profile of the case with added LPD values on a business day.

The profile shown in the Figure 4.4 belongs to the same day that the previous consumption option and its energy behaviour also consists of a low consumption between 9 PM and 8 AM and a medium-high consumption between the remaining hours. In this option, the main difference is that the lighting loads are created by adding LPD values to the numerical model. As the ASHRAE LPD values are higher than those calculated in the BC, the building's energy consumption increases slightly, which can be seen more clearly in the peak power of 35 kW. The schedules of all loads remain the same, the only thing that changes is the power of the lighting equipment that exists in each space. For this reason, it can be seen that in both the Figure 4.3 and the Figure 4.4, the power changes occur at the same hours but are of different magnitude.

4.2.3 Consumption with EPD values

It was obtained by adding the EPD values of Mahajan et al. [2017] in the numerical model, as well as the respective constant schedules. The Table 4.4 shows the general result obtained from the consumption with EPD values. It is important to clarify that all variables were calculated for an annual period.

Table 4.4: General results of the consumption with EPD values.

Variable	Result
E_{ec}	79.4 MWh
E_{lc}	20.4 MWh
C_{lpg}	0.1 MWh
C_{tot}	99.9 MWh
EUI	50.1 kWh/m^2

Unlike the Table 4.2, in Table 4.3 E_{ec} increases because of the use of the EPD values, so C_{tot} and EUI also increase. The EUI, calculated based on a gross floor area of 1993.6 m^2, is 50.1 kWh/m^2. The energy consumption of this consumption option is almost double that the one of the base case.

The Figure 4.5 shows the consumption profile of the case with added EPD values on a business day.

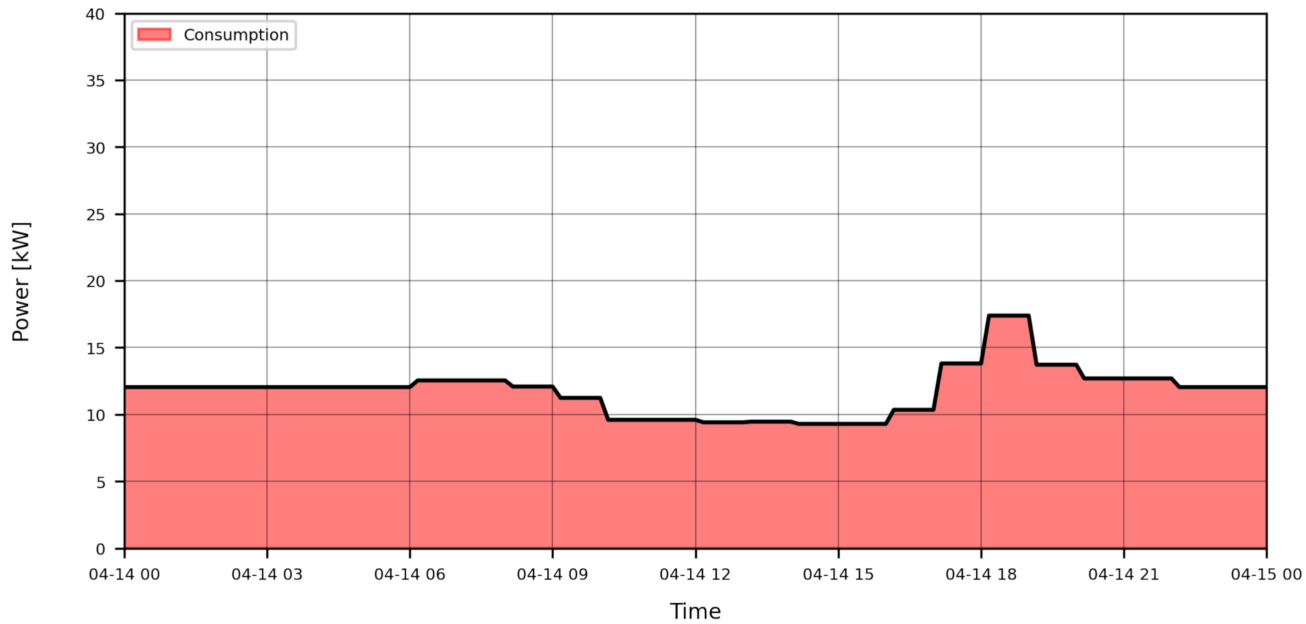


Figure 4.5: Consumption profile of the case with added EPD values on a business day.

The profile shown in the Figure 4.5 belongs to the same day that the two previous options, but the energy behaviour presents a great change. EPD values of Mahajan et al. [2017] do not use schedules of use and occupancy, but rather constant schedules, which consider that equipment within a space is on 8,760 hours a year. Using these schedules causes the annual consumption by equipment to flatten out and gives it that almost constant appearance of the Figure 4.5. The small power peaks and irregularities that can be observed between 4 PM and 8 PM are because of the consumption by lighting and LP gas, which have schedules of use and occupancy.

4.3 Scenarios and results of the evaluation

Nine scenarios were created with the two renewable generation options and three consumption options. In each of the scenarios, the four definitions were evaluated. The nine scenarios are listed below.

1. GF-BC: Generation on east and west façades with base case consumption.
2. GF-LPD: Generation on east and west façades with LPD consumption.
3. GF-EPD: Generation on east and west façades with EPD consumption.

4. GP-BC: Generation on north parking with base case consumption.
5. GP-LPD: Generation on north parking with base LPD consumption.
6. GP-EPD: Generation on north parking with base EPD consumption.
7. GFP-BC: Generation on east and west façades and north parking with base case consumption.
8. GFP-LPD: Generation on east and west façades and north parking with LPD consumption.
9. GFP-EPD: Generation on east and west façades and north parking with EPD consumption.

The results of each scenario and the evaluation of the four NZEB definitions are presented below.

4.3.1 GF-BC: Generation on east and west façades with base case consumption

In this scenario, renewable energy is generated through a PV system located on the east and west façades of the building. In addition, it has the base case consumption. The Table 4.5 shows the general result obtained from GF-BC scenario. It is important to clarify that all variables were calculated for an annual period.

Table 4.5: General results of GF-BC scenario.

Variable	**Result**
E_{ec}	43 MWh
E_{lc}	20.4 MWh
C_{lpg}	0.1 MWh
C_{tot}	63.5 MWh
GEN_{ren}	52.6 MWh

Since the use of any power density by gas equipment was not contemplated, the consumption of LP gas remains constant in all scenarios. The Figures 4.6 and 4.7 show, for the GF-BC scenario, the consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the days with the highest and lowest generation of the year, respectively. To select these days, only working days were taken into account, since these are the ones with the highest consumption and it is important to know how much of this is satisfied with renewable generation.

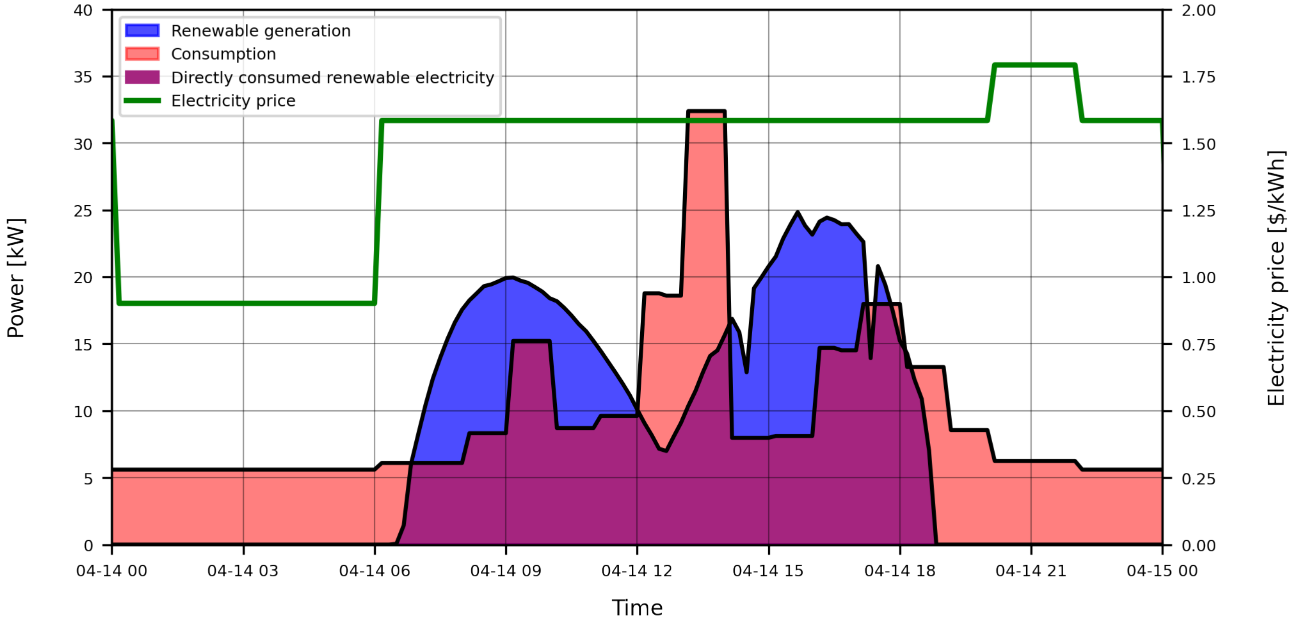


Figure 4.6: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the highest energy generated of the year for GF-BC scenario.

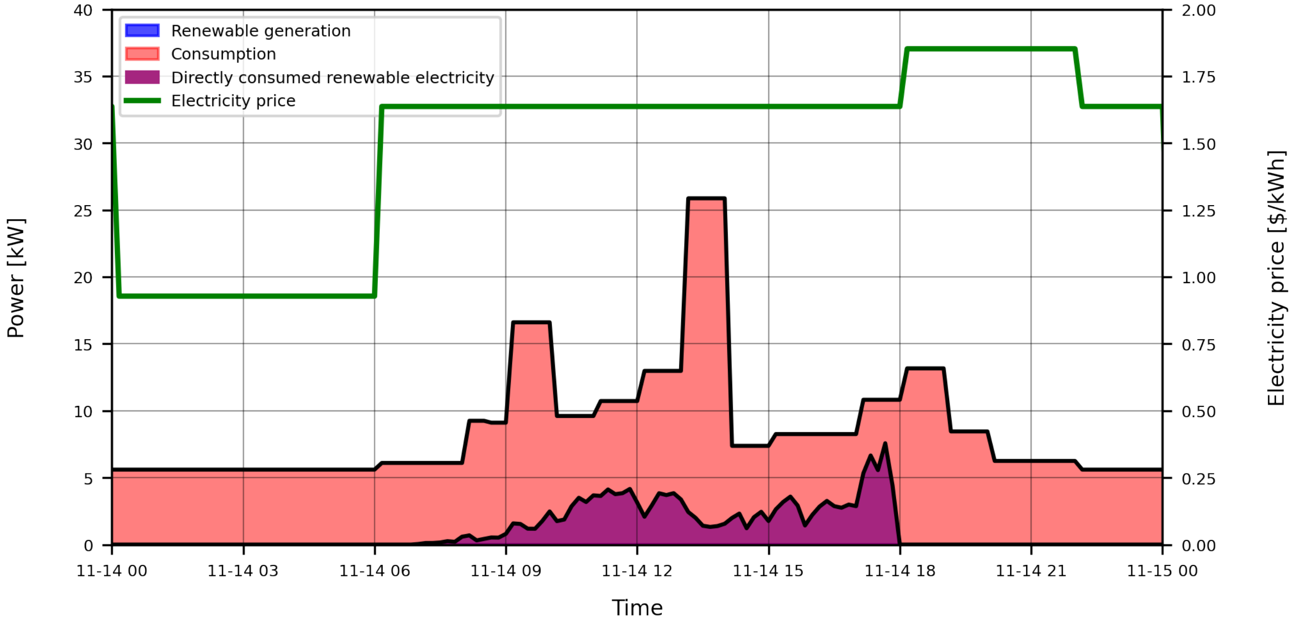


Figure 4.7: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the lowest energy generated of the year for GF-BC scenario.

The day with the highest renewable generation in the year for all the nine scenarios was Thursday April 14, while the day with the lowest generation for all the nine scenarios was Monday November 14. Since both are different days of the week, each has its own consumption profile. In this scenario, while the power peak on April 14 is approximately 33 kW, on November 14 it is 27 kW. In the Figure 4.6, renewable generation has this shape because of the east/west orientation of PV systems, so generation decreases as the sun is close to the zenith. Also there are several moments of the day where renewable generation is enough to satisfy the consumption of the building, so the excesses are exported to the grid. On the other hand, the shape of renewable generation in the Figure 4.7 may have been caused by a very cloudy or rainy day. As it is the day with the lowest renewable generation, all the generation is directly consumed, so it fails to satisfy the consumption of the building and there is no energy exported to the grid.

Three electricity rates are normally used in a day: the base rate, the intermediate rate and the peak rate. The first of these is the one with the lowest price per kWh and the last one is the one with the highest. It is important to mention that all the electricity rates that were used to simulate all the scenarios belong to the year 2022 and may vary depending on the hour, day, week or month. Figure 4.6 has information from April 14 and shows that from the beginning of the day until 6 AM the base rate is used, from 6 AM to 8 PM the intermediate energy rate is used, from 8 PM to 10 PM the peak rate is used and from 10 PM until the end of the day the intermediate rate is used again. Figure 4.7 has information from November 14. As it is a different day, there is a slight change in electricity prices and in the hours where the rates apply with respect to the Figure 4.6.

The Table 4.6 shows the detailed results of the evaluation of the four NZEB definitions in this scenario. The first column refers to the evaluated NZEB definition. In the second column, REN_{gen} refers to the renewable production necessary to meet the definition. In the third, GEN_{ren} is the current renewable production in the building. In the fourth column, $NZEB_{definition}$ represents the balance between the two previous columns. If this result of this column is positive, the definition is not met and if the result is negative, the definition is met. As a summary, the compliance with the definition is shown in column 5. In column 6 and 7, RER_{min} and RER_{real} values are shown, respectively. The RER_{min} value refers to the minimum proportion of renewable production that should be in the building with respect to the total site energy use to achieve a NZEB definition, while the RER_{real} value refers to the current proportion of renewable production in the building with respect to the total site energy use.

It is important to mention that, in cost-NZEB, the results are shown along with their associated price. For example, column REN_{gen} refers to the money the building owner must earn from the renewable energy generated in a year to meet the definition. The column GEN_{ren} refers to the money the building owner currently earns from the renewable energy generated in a year.

Table 4.6: Results of the evaluation of the NZEB definitions in GF-BC scenario.

Definition	REN_{gen}	GEN_{ren}	$NZEB_{definition}$	**Compliance**	RER_{min}	RER_{real}
site-NZEB	63.5 MWh	52.6 MWh	10.9 MWh	**Not achieved**	1	0.83
source-NZEB	63.4 MWh	52.6 MWh	10.8 MWh	**Not achieved**	1	0.83
cost-NZEB	172.2 MWh ($257,572)	52.6 MWh ($78,770)	119.6 MWh ($178,802)	**Not achieved**	2.71	0.83
emission-NZEB	51.1 MWh	52.6 MWh	-1.5 MWh	**Achieved**	0.81	0.83

Of the four definitions evaluated, only emission-NZEB is met, which means that the 52.6 MWh of renewable generation avoids the same or more CO2 emissions than those released by the 63.5 MWh of consumption by conventional sources. The RER_{min} refers to the ratio of annual minimum renewable generation that a building should have to meet an NZEB definition (REN_{gen}) with respect to its annual consumption ($TSEU$). The same $TSEU$ is used to calculate the RER_{min} of all definitions, however, the REN_{gen} of each of them is different, so almost all the definitions have a different value of RER_{min}. In the case of $RERreal$, it refers to the ratio of current annual renewable generation that a building has (GEN_{ren}) with respect to its $TSEU$. Both, GEN_{ren} and $TSEU$ are the same for all definitions, so all have the same RER_{real}. Figure 4.8 shows the RER_{min} and RER_{real} values of each evaluated definition.

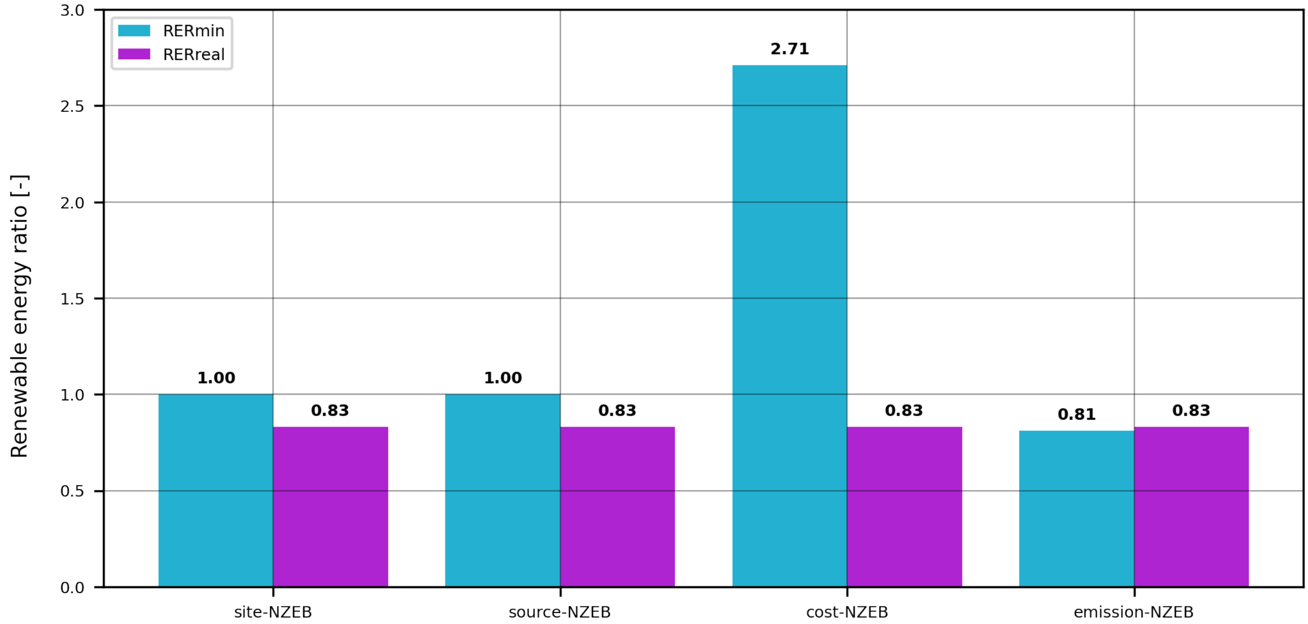


Figure 4.8: RERs comparison in the GF-BC scenario.

To achieve site-NZEB it is necessary that the annual REN_{gen} be equal to the annual $TSEU$ in a building, so, when calculating the RER_{min}, the result is equal to 1. The above explanation also applies to source-NZEB, since the only difference is the use of StSFs. Therefore, to meet site-NZEB and source-NZEB the building needs to satisfy 100% of its annual energy consumed through renewable generation. Since the building only satisfies 83%, both definitions are not met.

In the case of cost-NZEB, the REN_{gen} has a higher value than the previous two definitions, so when calculating its RER_{min}, higher values are obtained. To meet cost-NZEB, the moments when energy is generated matter more than the amount of energy generated. If peak rate is used between 6 pm and 10 pm, it is recommended that the building generates energy at that time so it can use that energy without paying for it. However, as the building only uses solar technology, it is not possible to generate energy during that time, so the building pays the kWh at its highest price. Therefore, to meet cost-NZEB, it must be a higher REN_{gen} to compensate the high payment in the moments with no generation. The most difficult definition to achieve is cost-NZEB, which has a RER_{min} value of 2.71, which means that the building must satisfy almost three times its annual energy consumption with renewable energy to achieve the definition. The building has a RER_{real} of 0.83, so it is a long way from meeting the definition.

Finally, to meet emission-NZEB, the building only has to generate 81% of the energy it consumes, which means that a kWh generated with renewable technology avoids more CO2 emissions than a kWh generated by conventional fossil fuels. According to the RER_{real} value, the building satisfies 83% of its consumption with renewable energy, which represents a higher proportion and is enough to meet emission-NZEB.

4.3.2 GF-LPD: Generation on east and west façades with LPD consumption

In this scenario, renewable energy is generated through a PV system located on the east and west façades of the building. In addition, it has the consumption with LPD values. The Table 4.7 shows the general result obtained from GF-LPD scenario. It is important to clarify that all variables were calculated for an annual period.

Table 4.7: General results of GF-LPD scenario

Variable	Result
E_{ec}	43 MWh
E_{lc}	23.8 MWh
C_{lpg}	0.1 MWh
C_{tot}	66.9 MWh
GEN_{ren}	52.6 MWh

The Figures 4.9 and 4.10 show, for the GF-LPD case, the consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the days with the highest and lowest generation of the year, respectively.

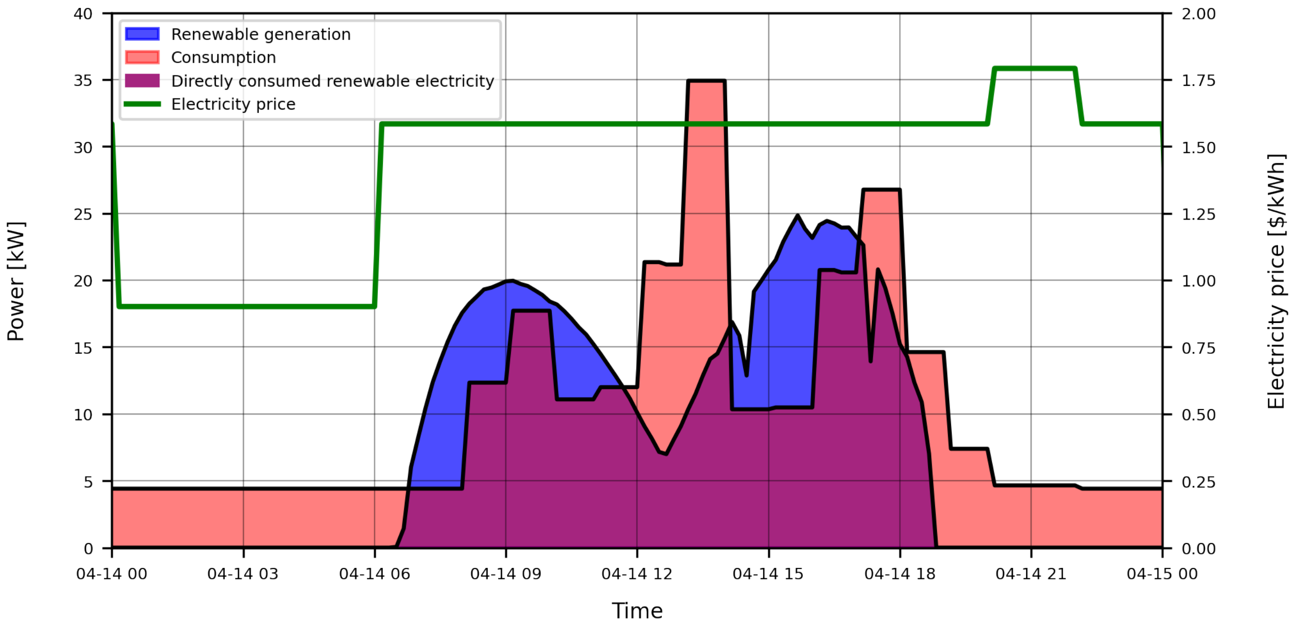


Figure 4.9: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the highest energy generated of the year for GF-LPD scenario.

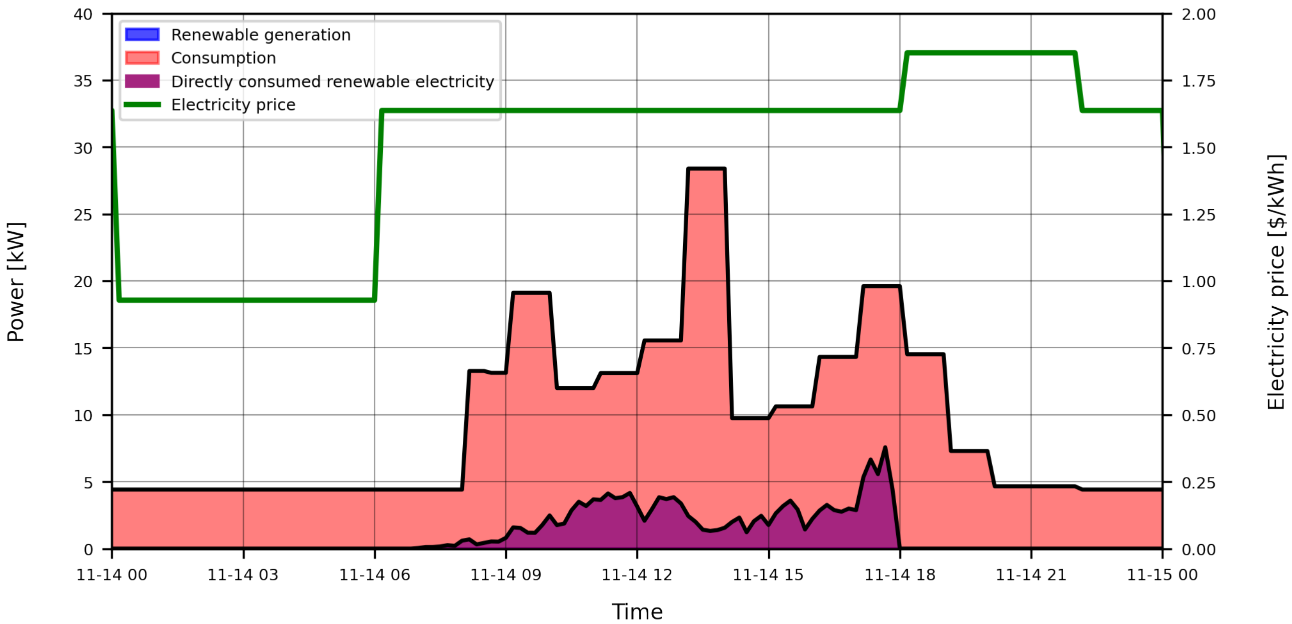


Figure 4.10: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the less energy generated of the year for GF-LPD scenario.

In this scenario, the building consumption increased due to the addition of the LPD values, so the power peak on April 14 is now approximately 35 kW and on November 14 is approximately 29 kW. The shape of renewable generation on the day of highest and lowest generation of the year is the same as the past scenario because there is no change in generation. The Table 4.8 shows the detailed results of the evaluation of the four NZEB definitions in this scenario.

Table 4.8: Results of the evaluation of the NZEB definitions in GF-LPD scenario.

Definition	REN_{gen}	GEN_{ren}	$NZEB_{definition}$	**Compliance**	RER_{min}	RER_{real}
site-NZEB	66.8 MWh	52.6 MWh	14.2 MWh	**Not achieved**	1	0.79
source-NZEB	66.8 MWh	52.6 MWh	14.2 MWh	**Not achieved**	1	0.79
cost-NZEB	181.6 MWh ($271,523)	52.6 MWh ($83,925)	129 MWh ($187,598)	**Not achieved**	2.72	0.79
emission-NZEB	53.8 MWh	52.6 MWh	1.2 MWh	**Not achieved**	0.81	0.79

Of the four definitions evaluated, none is met. The RER_{real} depends on REN_gen and $TSEU$. In this scenario GEN_{ren} continues to have the same value as in the previous one, however, $TSEU$ has an increase due to the addition of the LPD values. Therefore, a lower RER_{real} is obtained than in the previous scenario. The RER_{min} depends on REN_{gen} and $TSEU$. In this scenario, both REN_{gen} and $TSEU$ increase by adding the LPD values, so almost none of the RER_{min} changes with respect to the previous scenario. The only exception is with cost-NZEB and the slight increase occurs because there is now more energy imported and less exported. You must pay a little more for this increase in imported energy, so there must be a greater REN_{gen} to compensate that. Figure 4.11 shows the RER_{min} and RER_{real} values of each evaluated definition.

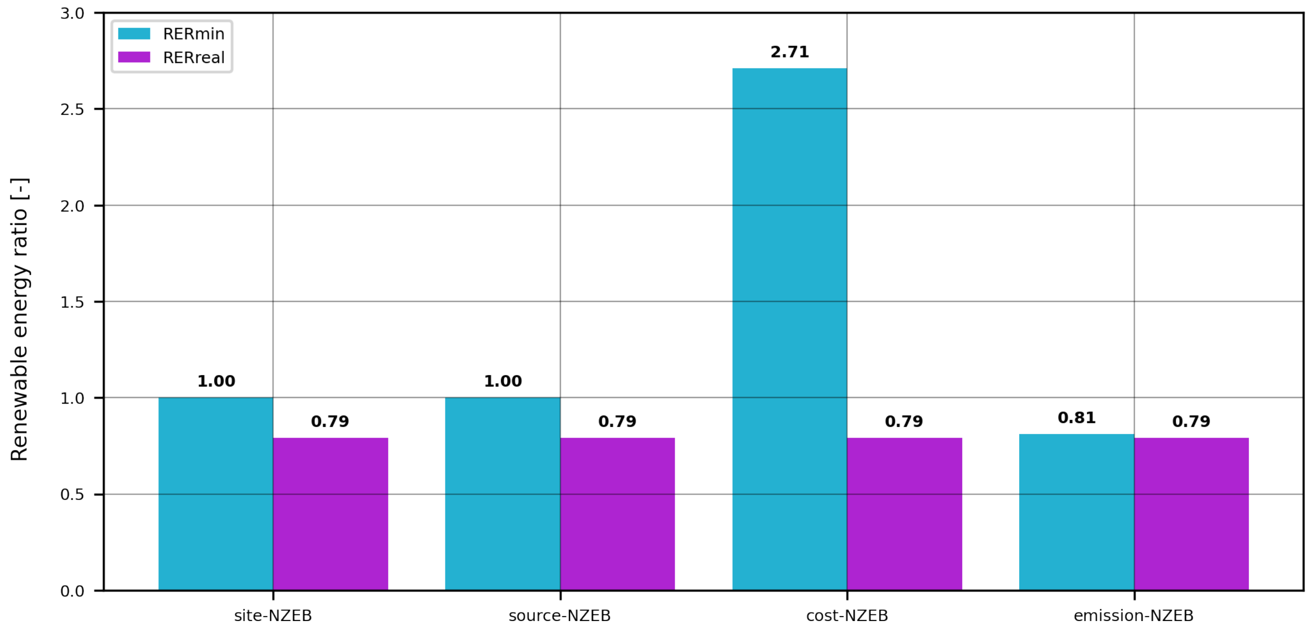


Figure 4.11: RERs comparison in the GF-LPD scenario.

To meet site-NZEB and source-NZEB the building needs to satisfy 100% of its annual energy consumed through renewable generation. Since the building only satisfies 79%, both definitions are not met. The RER_{min} value of cost-NZEB is 2.72, which means that the building must satisfy almost three times its annual energy consumption with renewable energy to achieve the definition. The building has a RER_{real} of 0.79, so it is a long way from meeting the definition. To meet emission-NZEB the building needs to satisfy 81% of its annual energy consumed through renewable generation. Since the building only satisfies 79%,the definition is not met.

4.3.3 GF-EPD: Generation on east and west façades with EPD consumption.

In this scenario, renewable energy is generated through a PV system located on the east and west façades of the building. In addition, it has the consumption with EPD values. The Table 4.9 shows the general result obtained from GF-EPD scenario. It is important to clarify that all variables were calculated for an annual period.

Table 4.9: General results of GF-EPD scenario

Variable	Result
E_{ec}	79.4 MWh
E_{lc}	20.4 MWh
C_{lpg}	0.1 MWh
C_{tot}	99.9 MWh
GEN_{ren}	52.6 MWh

The Figures 4.12 and 4.13 show the consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the days with the highest and lowest generation of the year, respectively.

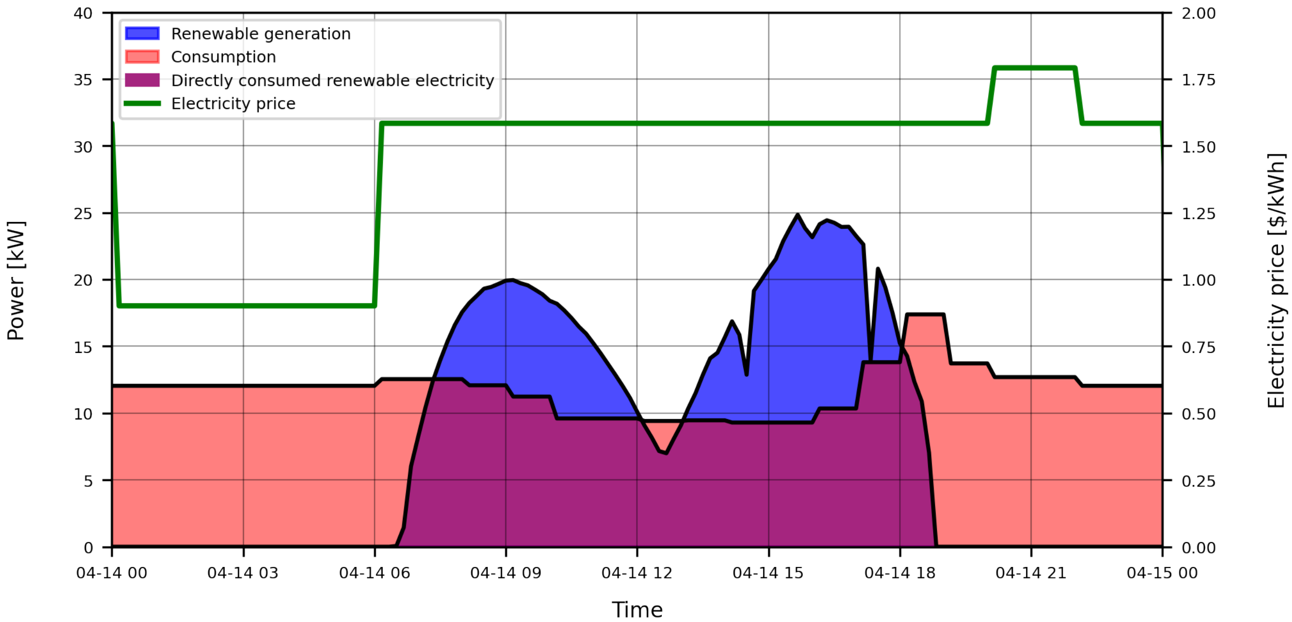


Figure 4.12: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the highest energy generated of the year for GF-EPD scenario.

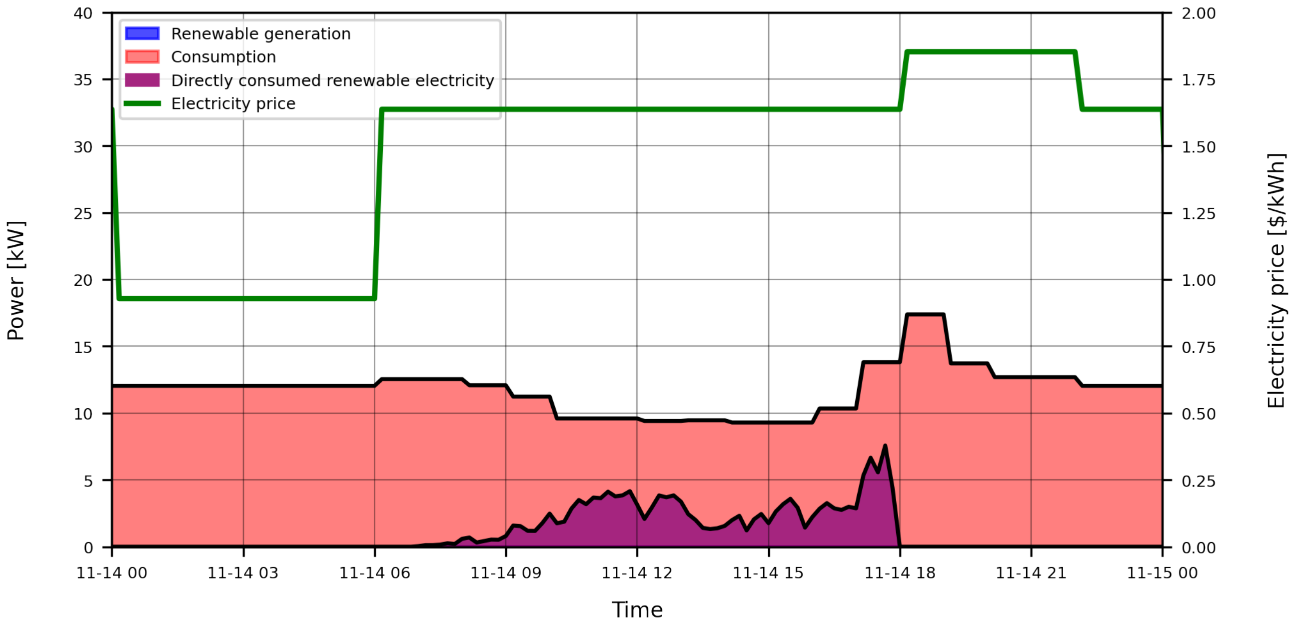


Figure 4.13: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the lowest energy generated of the year for GF-EPD scenario.

In this scenario the building consumption increases due to the addition of the EPD values, which are introduced to the numerical model along with a constant schedule. This causes consumption by equipment to be the same throughout the year and power peaks are reduced. The small peaks that can be seen in Figure 4.12 and Figure 4.13 are caused by the lighting loads, which still have base case usage schedules. In both figures there is an approximate peak power of 18 kW. The shape of renewable generation on the day of highest and lowest generation of the year is the same as the past scenario because there is no change in generation. The Table 4.10 shows the detailed results of the evaluation of the four NZEB definitions in this scenario.

Table 4.10: Results of the evaluation of the NZEB definitions in GF-EPD scenario.

Definition	REN_{gen}	GEN_{ren}	$NZEB_{definition}$	**Compliance**	RER_{min}	RER_{real}
site-NZEB	99.9 MWh	52.6 MWh	47.3 MWh	**Not achieved**	1	0.53
source-NZEB	99.8 MWh	52.6 MWh	47.2 MWh	**Not achieved**	1	0.53
cost-NZEB	173.8 MWh ($259,868)	52.6 MWh ($87,312)	121.2 MWh ($172,556)	**Not achieved**	1.74	0.53
emission-NZEB	80.4 MWh	52.6 MWh	27.8 MWh	**Not achieved**	0.81	0.53

Of the four definitions evaluated, none is met. In this scenario GEN_{ren} continues to have the same value as in the previous two, however, $TSEU$ has an increase due to the addition of the EPD values. Therefore, a lower RER_{real} is obtained than in the previous scenario. The RER_{min} depends on REN_{gen} and $TSEU$. In this scenario, both REN_{gen} and $TSEU$ increase by adding the EPD values, so almost none of the RER_{min} changes with respect to the previous scenario. The only exception is with cost-NZEB, where the RER_{min} is much lower than in the previous two scenarios. This behaviour is mainly because of the EPD values used to calculate the consumption of the equipment. Because Mahajan et al. [2017] calculated these values with the method based on consumption, the energy spent in each hour will be the same throughout the year, that is, the consumption is flattened and becomes constant throughout the year (as can be seen in Figures 4.12 and 4.13).

For example, in the space where an EPD value is added, it is considered that the same power is consumed at 2 am as at 2 pm and the rest of the hours of the day, when this does not occur in reality. In definitions such as site-NZEB, source-NZEB and emission-NZEB it does not matter so much because it only requires obtaining the annual energy consumption, but in cost-NZEB, the consumption peaks are the ones that make the energy consumed at certain time more expensive, so removing these peaks, by flattening and spreading the consumption over the year, can seriously affect the cost-NZEB evaluation. Therefore, the annual payment for electricity is lower than in the other scenarios and the REN_{gen} decreases, so the same applies to the RER_{min}. For this definition alone it is not recommended to use power density values that have been calculated with the method based on consumption. Figure 4.14 shows the RER_{min} and RER_{real} values of each evaluated definition.

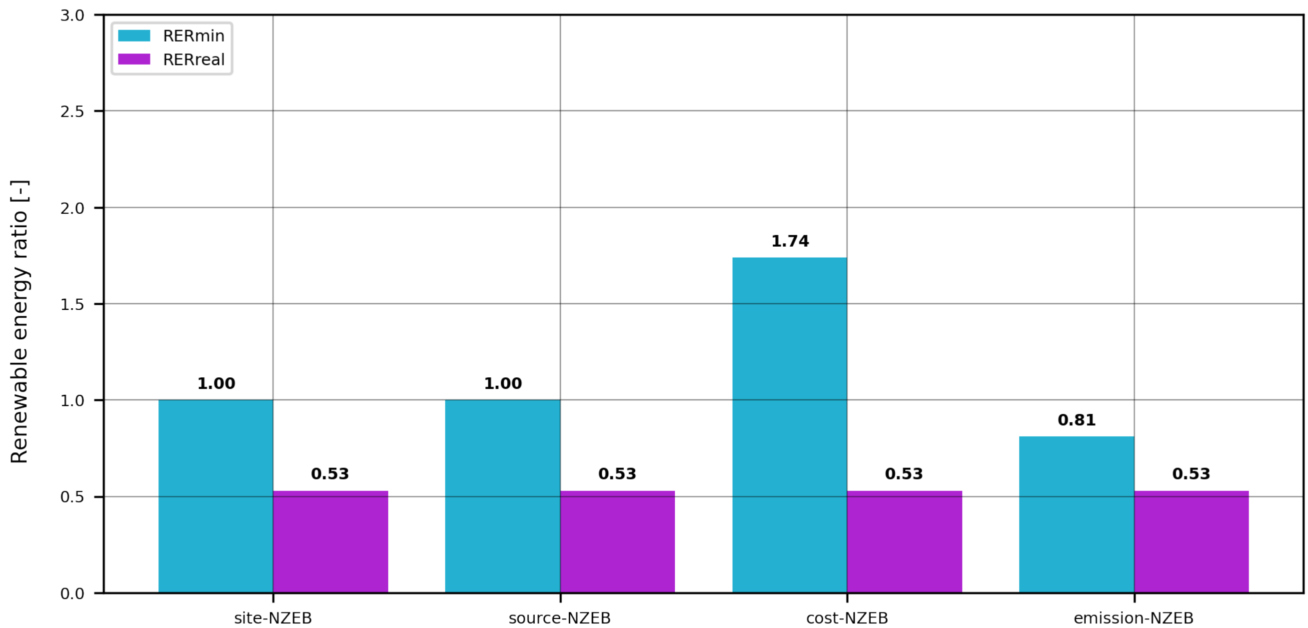


Figure 4.14: RERs comparison in the GF-EPD scenario.

To meet site-NZEB and source-NZEB the building needs to satisfy 100% of its annual energy consumed through renewable generation. Since the building only satisfies 53%, both definitions are not met. The RER_{min} value of cost-NZEB is 1.74, which means that the building must satisfy almost two times its annual energy consumption with renewable energy to achieve the definition. The building has a RER_{real} of 0.53, so the definition is not met. To meet emission-NZEB the building needs to satisfy 81% of its annual energy consumed through renewable generation. Since the building only satisfies 53%,the definition is not met.

4.3.4 GP-BC: Generation on north parking with base case consumption

In this scenario, renewable energy is generated through a PV system located on the North parking of the building. In addition, it has the base case consumption. The Table 4.11 shows the general result obtained from GP-BC scenario. It is important to clarify that all variables were calculated for an annual period.

Table 4.11: General results of GP-BC scenario

Variable	Result
E_{ec}	43 MWh
E_{lc}	20.4 MWh
C_{lpg}	0.1 MWh
C_{tot}	63.5 MWh
GEN_{ren}	88.5 MWh

The Figures 4.15 and 4.16 show the consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the days with the highest and lowest generation of the year, respectively.

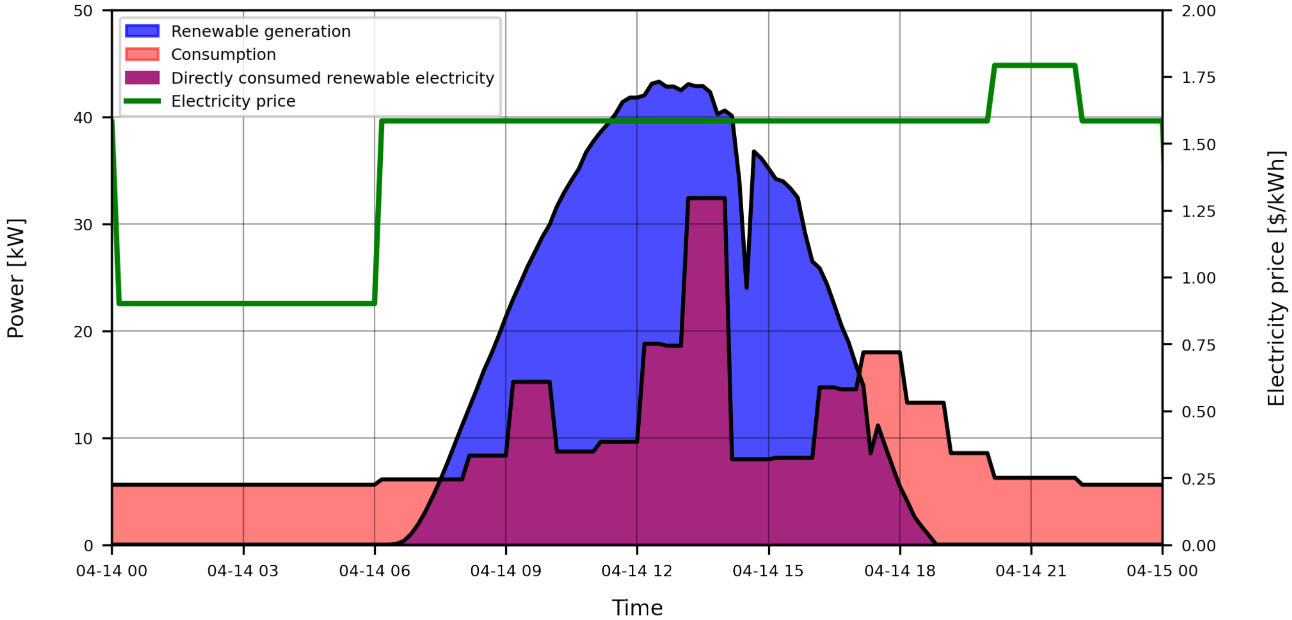


Figure 4.15: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the most energy generated of the year for GP-BC scenario.

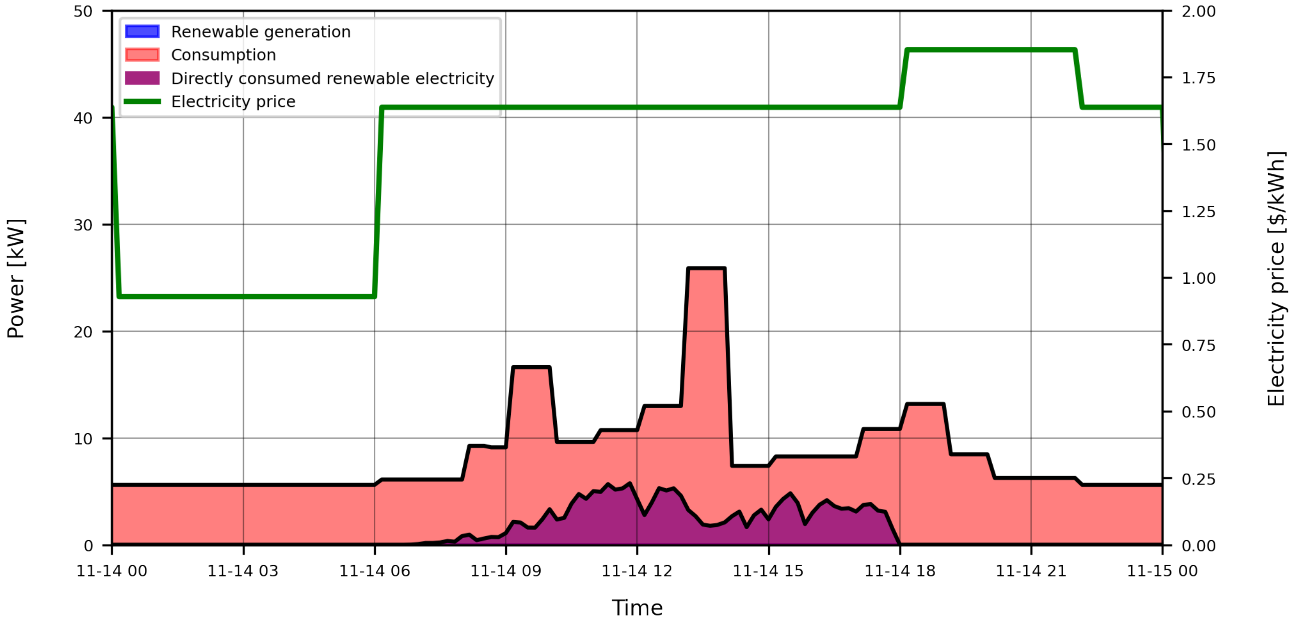


Figure 4.16: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the lowest energy generated of the year for GP-BC scenario.

Unlike the PV systems installed on the east and west façades, the north parking system, thanks to its location, does not present any shading as the sun approaches the zenith (as can be seen in Figure 4.15). The energy generated, in addition to being greater than that of the other system, is also produced precisely at the hours when there is the most consumption in the institute, so there is more renewable energy consumed directly. The Table 4.12 shows the detailed results of the evaluation of the four NZEB definitions in this scenario.

Table 4.12: Results of the evaluation of the NZEB definitions in GP-BC scenario.

Definition	REN_{gen}	GEN_{ren}	$NZEB_{definition}$	**Compliance**	RER_{min}	RER_{real}
site-NZEB	63.5 MWh	88.5 MWh	-25.0 MWh	**Achieved**	1	1.39
source-NZEB	63.4 MWh	88.5 MWh	-25.1 MWh	**Achieved**	1	1.39
cost-NZEB	172.2 MWh ($257,572)	88.5 MWh ($132,325)	83.7 MWh ($125,247)	**Not achived**	2.71	1.39
emission-NZEB	51.1 MWh	88.5 MWh	-37.4 MWh	**Achieved**	0.81	1.39

Of the four definitions evaluated, only cost-NZEB is not met. The RER_{real} depends on GEN_ren and $TSEU$. In this scenario GEN_{ren} increases and $TSEU$ has the same value as in the GF-BC scenario. Therefore, a higher RER_{real} is obtained than in the three previous scenarios. The RER_{min} depends on REN_{gen} and $TSEU$. In this scenario, both REN_{gen} and $TSEU$ have the same values as the GF-BC scenario, so the RER_{min} values of all definitions are also the same. REN_{gen} of cost-NZEB depends on the time at which the energy is generated. Although their generation has different shapes and quantities, both the GF-BC scenario and the GP-BC scenario have the same REN_{gen}, since the generation of both scenarios is between 6 AM and 6 PM, period where the price per kWh remains constant, as can be seen in Figure 4.6 and Figure 4.15. Therefore, the kWh generated in both scenarios are worth exactly the same and their REN_{gen} is the same. Figure 4.17 shows the RER_{min} and RER_{real} values of each evaluated definition.

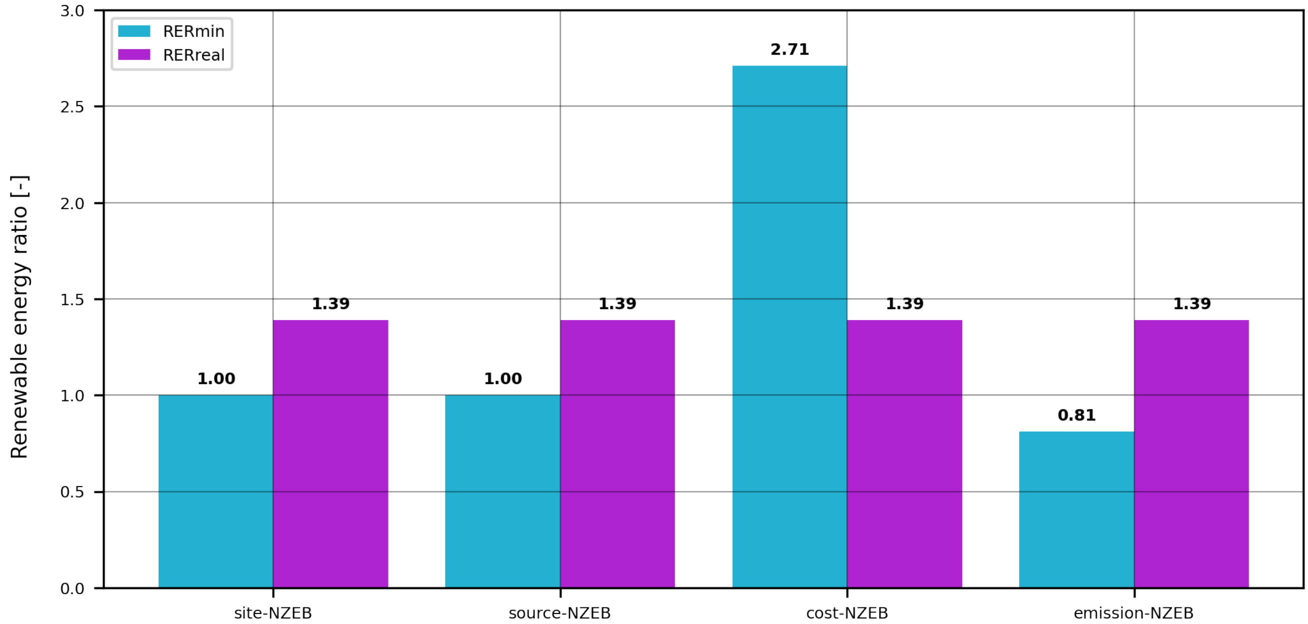


Figure 4.17: RERs comparison in the GP-BC scenario.

To meet site-NZEB and source-NZEB the building needs to satisfy 100% of its annual energy consumed through renewable generation. Since the building satisfies 139%, both definitions are met. The RER_{min} value of cost-NZEB is 2.71, which means that the building must satisfy almost three times its annual energy consumption with renewable energy to achieve the definition. The building has a RER_{real} of 1.39, so the definition is not met. To meet emission-NZEB the building needs to satisfy 81% of its annual energy consumed through renewable generation. Since the building satisfies 139%,the definition is met.

4.3.5 GP-LPD: Generation on north parking with base LPD consumption

In this scenario, renewable energy is generated through a PV system located on the North parking of the building. In addition, it has the consumption with LPD values. The Table 4.13 shows the general result obtained from GP-LPD scenario. It is important to clarify that all variables were calculated for an annual period.

Table 4.13: General results of GP-LPD scenario

Variable	Result
E_{ec}	43 MWh
E_{lc}	23.8 MWh
C_{lpg}	0.1 MWh
C_{tot}	66.9 MWh
GEN_{ren}	88.5 MWh

The Figures 4.18 and 4.19 show the consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the days with the highest and lowest generation of the year, respectively.

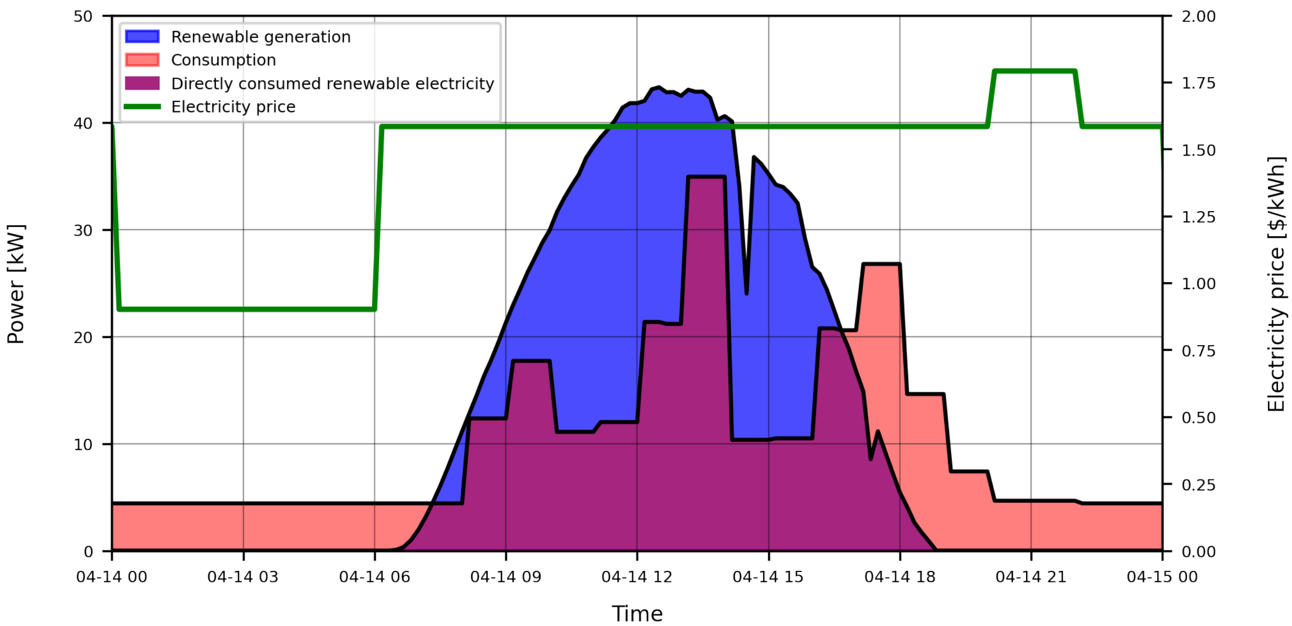


Figure 4.18: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the highest energy generated of the year for GP-LPD scenario.

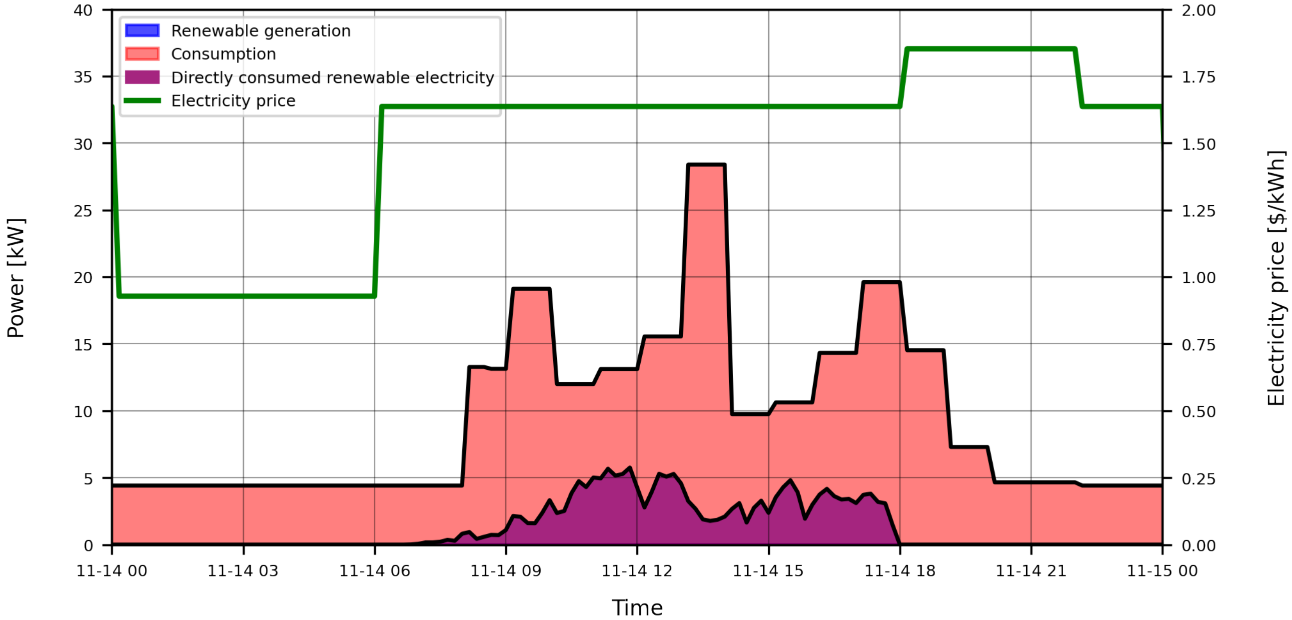


Figure 4.19: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the lowest energy generated of the year for GP-LPD scenario.

In this scenario, the building consumption increased due to the addition of the LPD values and the north parking system does not present any shading as the sun approaches. The shape of renewable generation on the day of highest and lowest generation of the year is the same as the past scenario because there is no change in generation. The energy generated is produced precisely at the hours when there is the most consumption in the institute, so there is more renewable energy consumed directly. The Table 4.14 shows the detailed results of the evaluation of the four NZEB definitions in this scenario.

Table 4.14: Results of the evaluation of the NZEB definitions in GP-LPD scenario.

Definition	REN_{gen}	GEN_{ren}	$NZEB_{definition}$	**Compliance**	RER_{min}	RER_{real}
site-NZEB	66.8 MWh	88.5 MWh	-21.7 MWh	**Achieved**	1	1.32
source-NZEB	66.8 MWh	88.5 MWh	-21.7 MWh	**Achieved**	1	1.32
cost-NZEB	181.7 MWh ($271,523)	88.5 MWh ($137,480)	93.2 MWh ($134,043)	**Not achieved**	2.72	1.32
emission-NZEB	53.8 MWh	88.5 MWh	-34.7 MWh	**Achieved**	0.81	1.32

Of the four definitions evaluated, only cost-NZEB is not achieved. In this scenario GEN_{ren} continues to have the same value as in the previous one, however, $TSEU$ has an increase due to the addition of the LPD values. Therefore, a lower RER_{real} is obtained than in the previous scenario but higher than the GF-LPD scenario. The RER_{min} depends on REN_{gen} and $TSEU$. In this scenario, both REN_{gen} and $TSEU$ increase by adding the LPD values, so almost none of the RER_{min} changes with respect to the previous scenario. The only exception is with cost-NZEB and the slight increase occurs because there is now more energy imported and less exported. This scenario has the same RER_{min} value as the BF-LPD scenario because $TSEU$ and REN_gen do not change either. Figure 4.20 shows the RER_{min} and RER_{real} values of each evaluated definition.

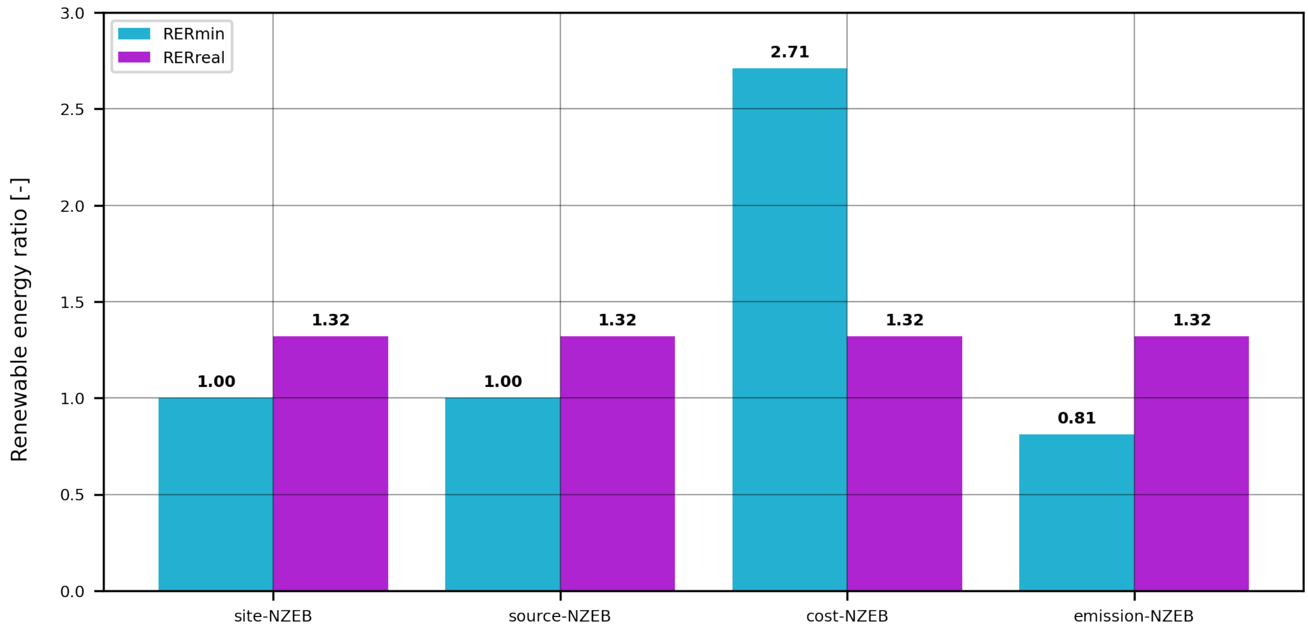


Figure 4.20: RERs comparison in the GP-LPD scenario.

To meet site-NZEB and source-NZEB the building needs to satisfy 100% of its annual energy consumed through renewable generation. Since the building satisfies 132%, both definitions are met. The RER_{min} value of cost-NZEB is 2.72, which means that the building must satisfy almost three times its annual energy consumption with renewable energy to achieve the definition. The building has a RER_{real} of 1.32, so the definition is not met. To meet emission-NZEB the building needs to satisfy 81% of its annual energy consumed through renewable generation. Since the building satisfies 132%,the definition is met.

4.3.6 GP-EPD: Generation on north parking with base EPD consumption

In this scenario, renewable energy is generated through a PV system located on the North parking of the building. In addition, it has the consumption with EPD values. The Table 4.15 shows the general result obtained from GP-EPD scenario. It is important to clarify that all variables were calculated for an annual period.

Table 4.15: General results of GP-EPD scenario

Variable	**Result**
E_{ec}	79.4 MWh
E_{lc}	20.4 MWh
C_{lpg}	0.1 MWh
C_{tot}	99.9 MWh
GEN_{ren}	88.5 MWh

The Figures 4.21 and 4.22 show the consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the days with the highest and lowest generation of the year, respectively.

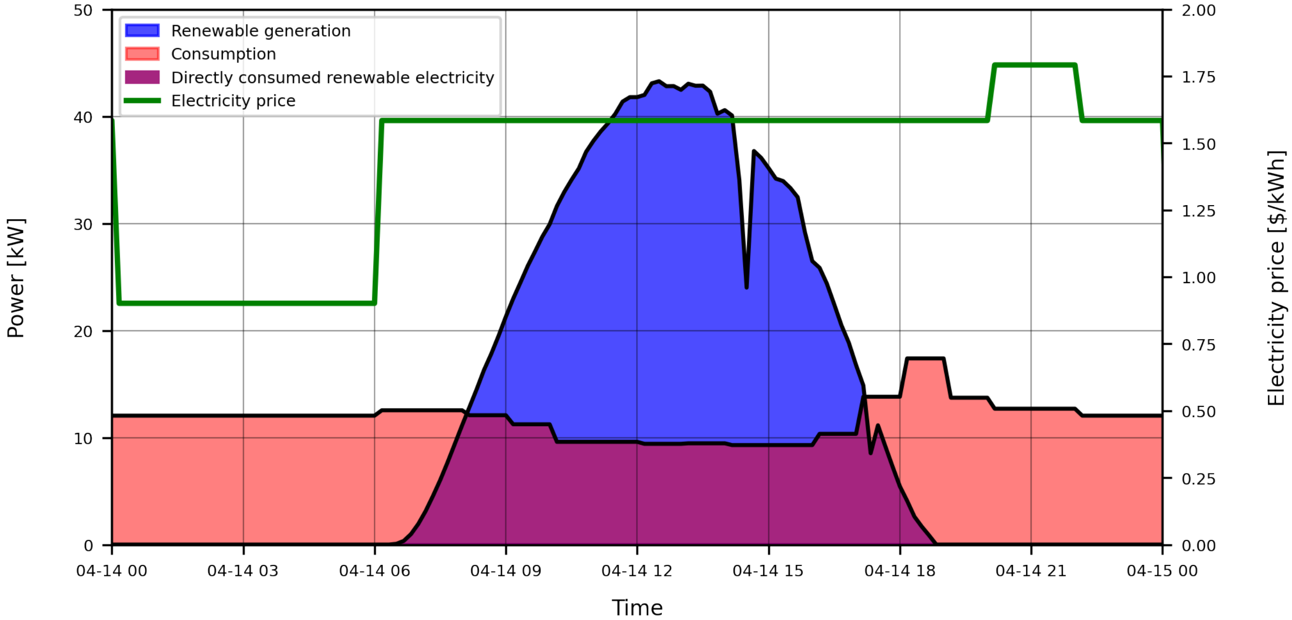


Figure 4.21: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the highest energy generated of the year for GP-EPD scenario.

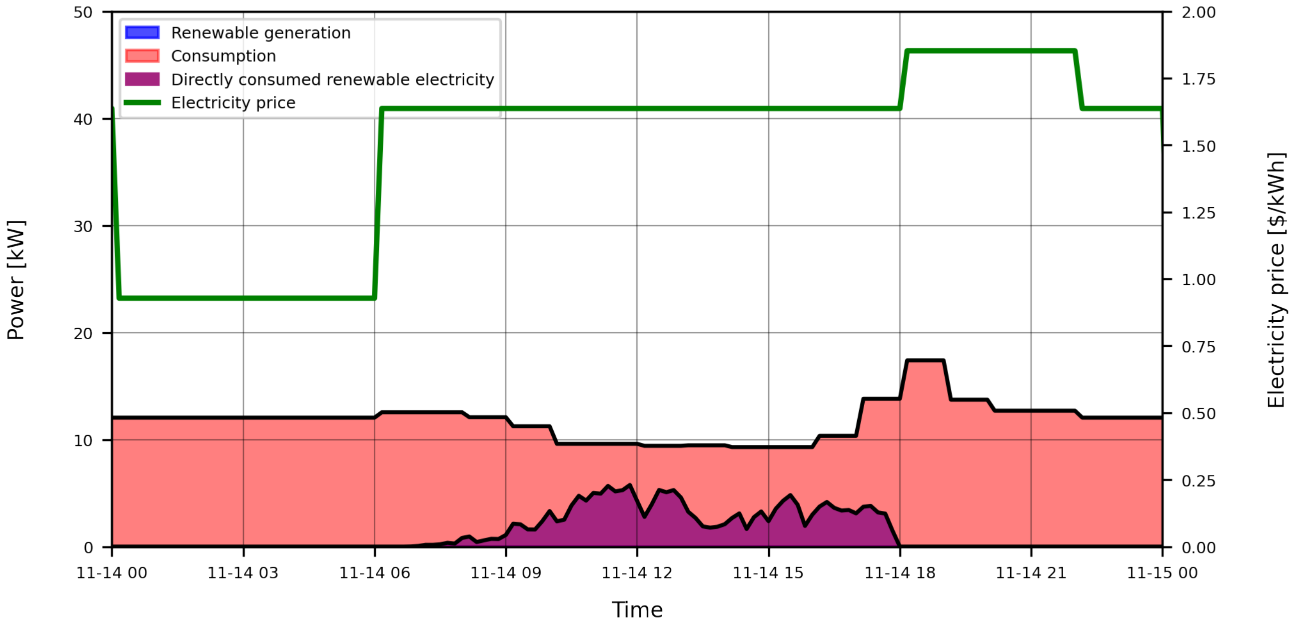


Figure 4.22: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the lowest energy generated of the year for GP-EPD scenario.

In this scenario the building consumption increases due to the addition of the EPD values, which are introduced to the numerical model along with a constant schedule. This causes consumption by equipment to be the same throughout the year and power peaks are reduced. The small peaks that can be seen in Figure 4.21 and Figure 4.22 are caused by the lighting loads, which still have base case usage schedules. The north parking system does not present any shading as the sun approaches. The energy generated is produced precisely at the hours when there is the most consumption in the institute, so there is more renewable energy consumed directly. The Table 4.16 shows the detailed results of the evaluation of the four NZEB definitions in this scenario.

Table 4.16: Results of the evaluation of the NZEB definitions in GP-EPD scenario.

Definition	REN_{gen}	GEN_{ren}	$NZEB_{definition}$	**Compliance**	RER_{min}	RER_{real}
site-NZEB	99.9 MWh	88.5 MWh	11.4 MWh	**Not achieved**	1	0.89
source-NZEB	99.8 MWh	88.5 MWh	11.3 MWh	**Not achieved**	1	0.89
cost-NZEB	173.8 MWh ($ 259,868)	88.5 MWh ($140,866)	85.3 MWh ($119,002)	**Not achieved**	1.74	0.89
emission-NZEB	80.4 MWh	88.5 MWh	-8.1 MWh	**Achieved**	0.81	0.89

Of the four definitions evaluated, only emission-NZEB is achieved. In this scenario GEN_{ren} continues to have the same value as in the previous two, however, $TSEU$ has an increase due to the addition of the EPD values. Therefore, a lower RER_{real} is obtained than in the previous scenario but higher than the GF-EPD scenario. The RER_{min} depends on REN_{gen} and $TSEU$. In this scenario, both REN_{gen} and $TSEU$ increase by adding the EPD values, so almost none of the RER_{min} changes with respect to the previous scenario. The only exception is with cost-NZEB and the slight increase occurs because there is now more energy imported and less exported. This scenario has the same RER_{min} value as the BF-EPD scenario because $TSEU$ and REN_gen do not change either. Figure 4.23 shows the RER_{min} and RER_{real} values of each evaluated definition.

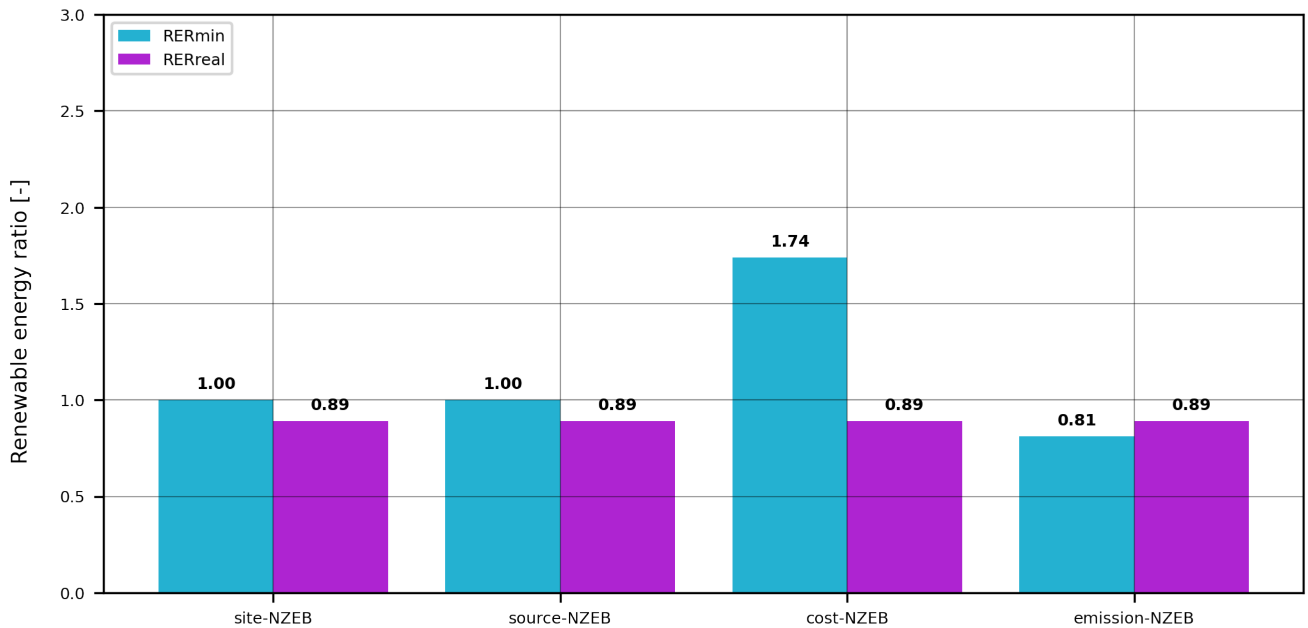


Figure 4.23: RERs comparison in the GP-EPD scenario.

To meet site-NZEB and source-NZEB the building needs to satisfy 100% of its annual energy consumed through renewable generation. Since the only building satisfies 89%, both definitions are not met. The RER_{min} value of cost-NZEB is 1.74, which means that the building must satisfy almost two times its annual energy consumption with renewable energy to achieve the definition. The building has a RER_{real} of 0.89, so the definition is not met. To meet emission-NZEB the building needs to satisfy 81% of its annual energy consumed through renewable generation. Since the building satisfies 89%,the definition is met.

4.3.7 GFP-BC: Generation on east and west façades and north parking with base case consumption

In this scenario, renewable energy is generated through two PV systems, one located on the east and west façades and the other on the North parking of the building. In addition, it has the base case consumption. The Table 4.17 shows the general result obtained from GFP-BC scenario. It is important to clarify that all variables were calculated for an annual period.

Table 4.17: General results of GFP-BC scenario

Variable	Result
E_{ec}	43 MWh
E_{lc}	20.4 MWh
C_{lpg}	0.1 MWh
C_{tot}	63.5 MWh
GEN_{ren}	141.1 MWh

The Figures 4.24 and 4.25 show the consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the days with the highest and lowest generation of the year, respectively.

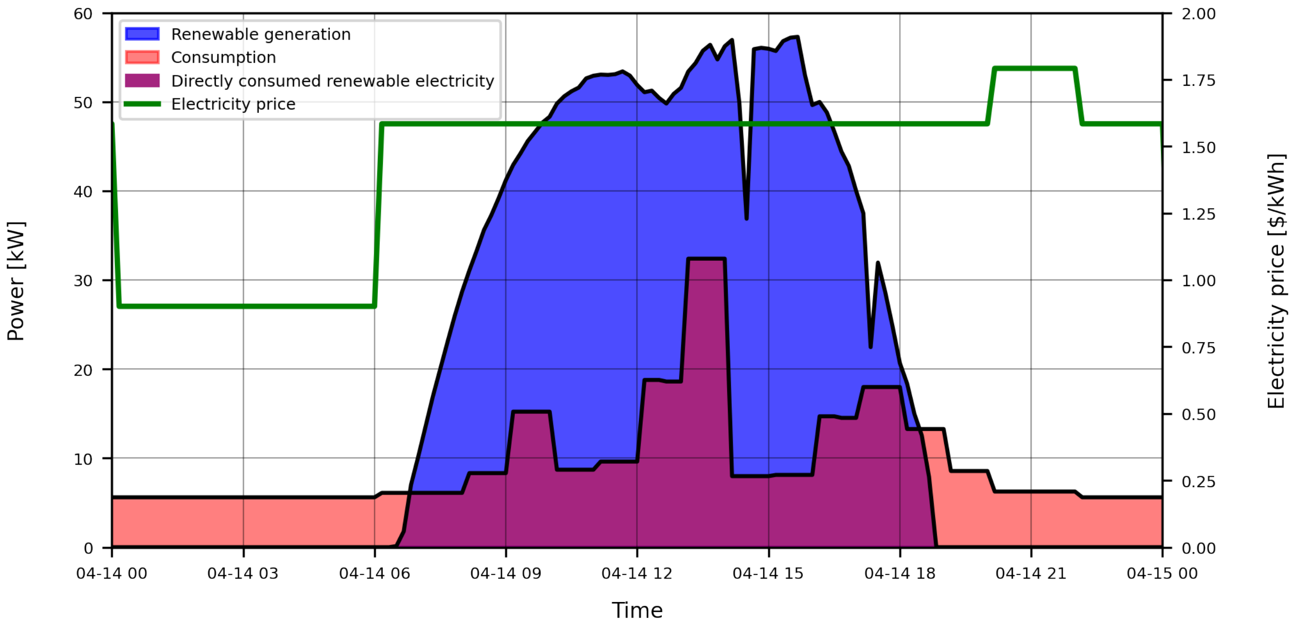


Figure 4.24: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the highest energy generated of the year for GFP-BC scenario.

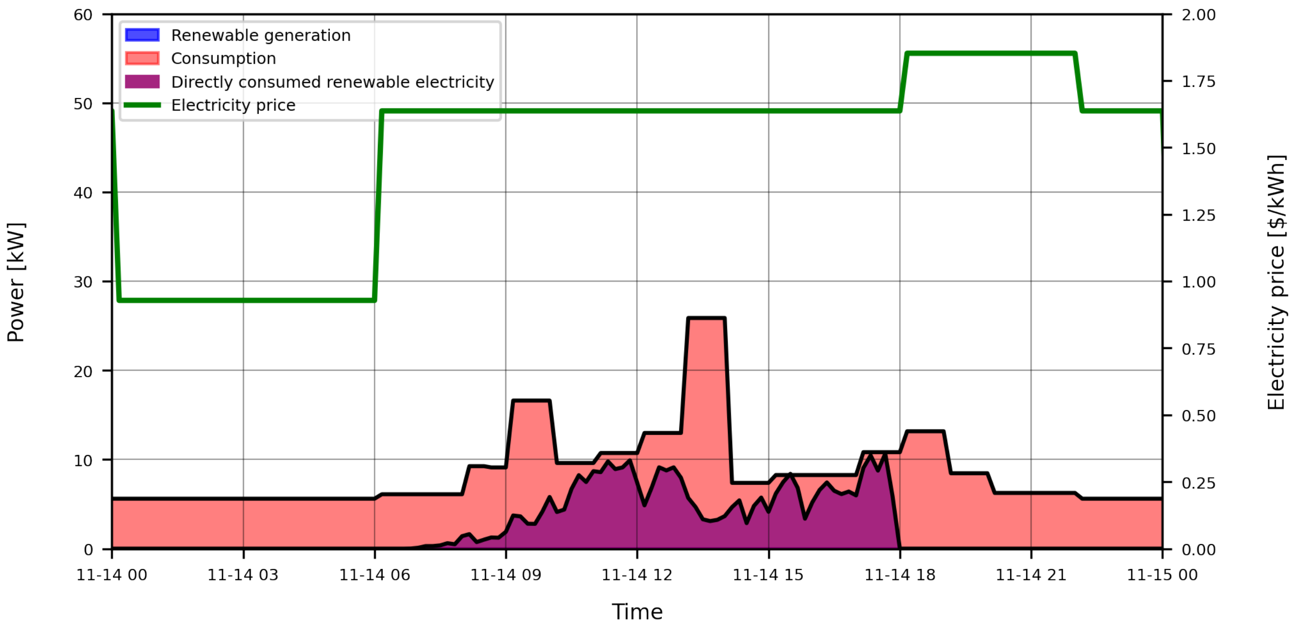


Figure 4.25: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the lowest energy generated of the year for GFP-BC scenario.

In this scenario, the generation of both PV systems is combined. Therefore, as seen in the Figure 4.24, no shading as the sun approaches to zenith. This scenario has the largest possible renewable generation, which is produced precisely during the hours with the highest consumption at the institute, so it is also the scenario with the largest directly consumed renewable electricity. Table 4.18 shows the detailed results of the evaluation of the four NZEB definitions in this scenario.

Table 4.18: Results of the evaluation of the NZEB definitions in GFP-BC scenario.

Definition	REN_{gen}	GEN_{ren}	$NZEB_{definition}$	**Compliance**	RER_{min}	RER_{real}
site-NZEB	63.5 MWh	141.1 MWh	-77.6 MWh	**Achieved**	1	2.22
source-NZEB	63.4 MWh	141.1 MWh	-77.7 MWh	**Achieved**	1	2.22
cost-NZEB	172.3 MWh ($257,572)	141.1 MWh ($211,095)	31.2 MWh ($46,477)	**Not achieved**	2.71	2.22
emission-NZEB	51.1 MWh	141.1 MWh	-90 MWh	**Achieved**	0.81	2.22

Of the four definitions evaluated, only cost-NZEB is not met. The RER_{real} depends on GEN_ren and $TSEU$. In this scenario GEN_{ren} increases and $TSEU$ has the same value as in the GF-BC and GP-BC scenarios. Therefore, a higher RER_{real} is obtained than in the six previous scenarios. The RER_{min} depends on REN_{gen} and $TSEU$. In this scenario, both REN_{gen} and $TSEU$ have the same values as the GF-BC and GP-BC scenarios, so the RER_{min} values of all definitions are also the same. REN_{gen} of cost-NZEB depends on the time at which the energy is generated. Although their generation has different shapes and quantities, the GF-BC scenario, GP-BC scenario and this scenario have the same REN_{gen}, since the generation of the three scenarios is between 6 AM and 6 PM, period where the price per kWh remains constant, as can be seen in Figure 4.24 and Figure 4.27. Therefore, the kWh generated in the three scenarios are worth exactly the same and their REN_{gen} is the same. Figure 4.26 shows the RER_{min} and RER_{real} values of each evaluated definition.

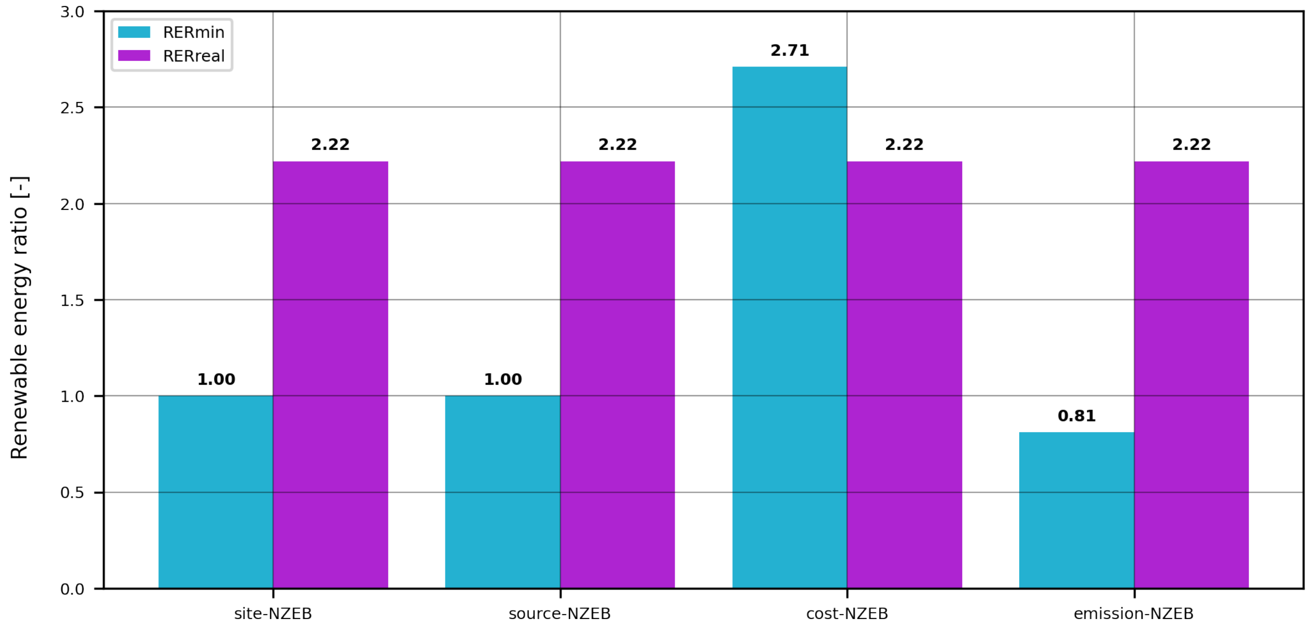


Figure 4.26: RERs comparison in the GFP-BC scenario.

To meet site-NZEB and source-NZEB the building needs to satisfy 100% of its annual energy consumed through renewable generation. Since the building satisfies 222%, both definitions are met. The RER_{min} value of cost-NZEB is 2.71, which means that the building must satisfy almost two times its annual energy consumption with renewable energy to achieve the definition. The building has a RER_{real} of 2.22, so the definition is not met. To meet emission-NZEB the building needs to satisfy 81% of its annual energy consumed through renewable generation. Since the building satisfies 222%,the definition is met.

4.3.8 GFP-LPD: Generation on east and west façades and north parking with LPD consumption

In this scenario, renewable energy is generated through two PV systems, one located on the east and west façades and the other on the North parking of the building. In addition, it has the consumption with LPD values. The Table 4.19 shows the general result obtained from GFP-LPD scenario. It is important to clarify that all variables were calculated for an annual period.

Table 4.19: General results of GFP-LPD scenario

Variable	Result
E_{ec}	43 MWh
E_{lc}	23.8 MWh
C_{lpg}	0.1 MWh
C_{tot}	66.9 MWh
GEN_{ren}	141.1 MWh

The Figures 4.27 and 4.28 show the Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the days with the highest and lowest generation of the year, respectively.

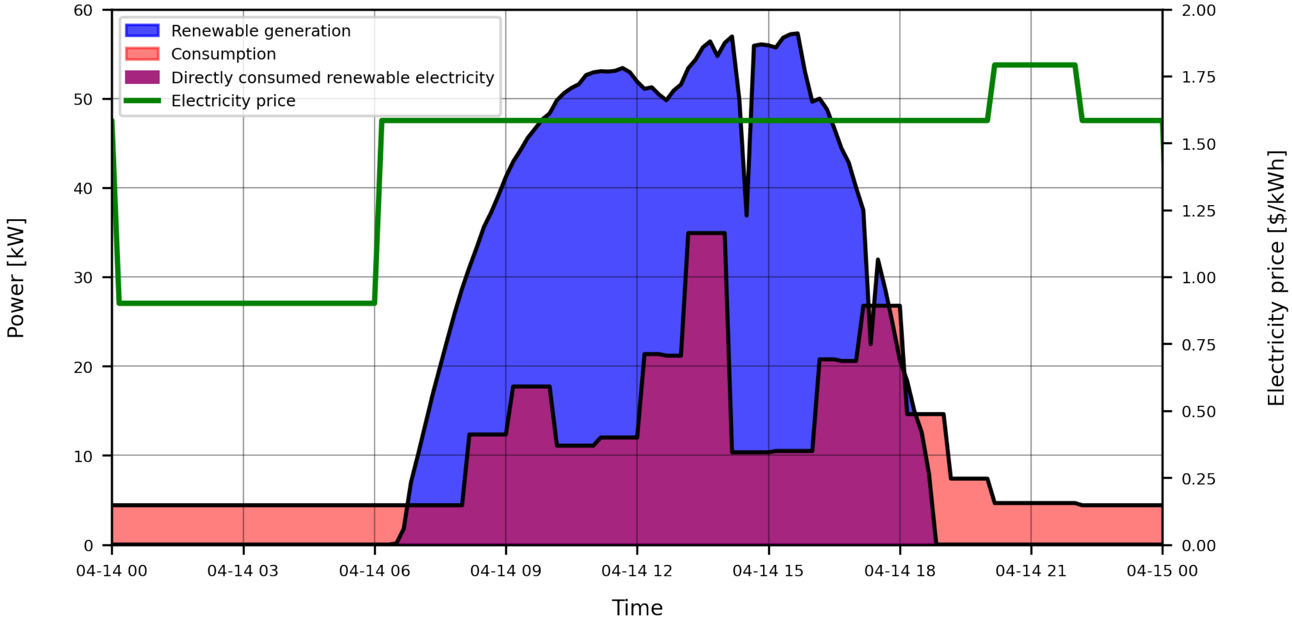


Figure 4.27: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the most energy generated of the year for GFP-LPD scenario.

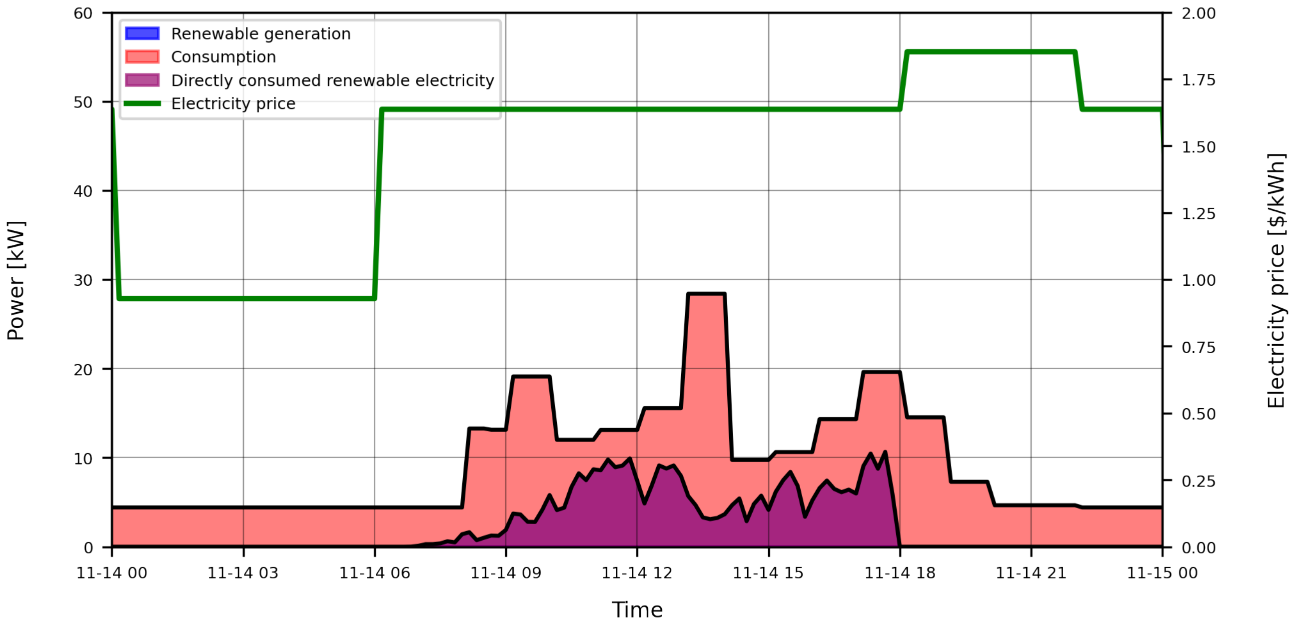


Figure 4.28: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the lowest energy generated of the year for GFP-LPD scenario.

In this scenario, the building consumption increased due to the addition of the LPD values and the generation of both PV systems is combined. Therefore, as seen in the Figure 4.27, no shading as the sun approaches to zenith. This scenario has the largest possible renewable generation, which is produced precisely during the hours with the highest consumption at the institute, so it is also the scenario with the largest directly consumed renewable electricity. Table 4.20 shows the detailed results of the evaluation of the four NZEB definitions in this scenario.

Table 4.20: Results of the evaluation of the NZEB definitions in GFP-LPD scenario.

Definition	REN_{gen}	GEN_{ren}	$NZEB_{definition}$	Compliance	RER_{min}	RER_{real}
site-NZEB	66.8 MWh	141.1 MWh	-74.3 MWh	**Achieved**	1	2.11
source-NZEB	66.8 MWh	141.1 MWh	-74.3 MWh	**Achieved**	1	2.11
cost-NZEB	181.7 MWh ($271,523)	141.1 MWh ($216,250)	40.6 MWh ($55,273)	**Not achieved**	2.72	2.11
emission-NZEB	53.8 MWh	141.1 MWh	-87.3 MWh	**Achieved**	0.81	2.11

Of the four definitions evaluated, only cost-NZEB is not achieved. In this scenario GEN_{ren} continues to have the same value as in the previous one, however, $TSEU$ has an increase due to the addition of the LPD values. Therefore, a lower RER_{real} is obtained than in the previous scenario but higher than the GF-LPD and GP-LPD scenarios. The RER_{min} depends on REN_{gen} and $TSEU$. In this scenario, both REN_{gen} and $TSEU$ increase by adding the LPD values, so almost none of the RER_{min} changes with respect to the previous scenario. The only exception is with cost-NZEB and the slight increase occurs because there is now more energy imported and less exported. This scenario has the same RER_{min} value as the BF-LPD scenario because $TSEU$ and REN_{gen} do not change either. Figure 4.29 shows the RER_{min} and RER_{real} values of each evaluated definition. REN_{gen} of cost-NZEB depends on the time at which the energy is generated. Although their generation has different shapes and quantities, the GF-LPD scenario, GP-LPD scenario and this scenario have the same REN_{gen}, since the generation of the three scenarios is between 6 AM and 6 PM, period where the price per kWh remains constant, as can be seen in Figure 4.27 and Figure 4.27. Therefore, the kWh generated in the three scenarios are worth exactly the same and their REN_{gen} is the same. Figure 4.29 shows the RER_{min} and RER_{real} values of each evaluated definition.

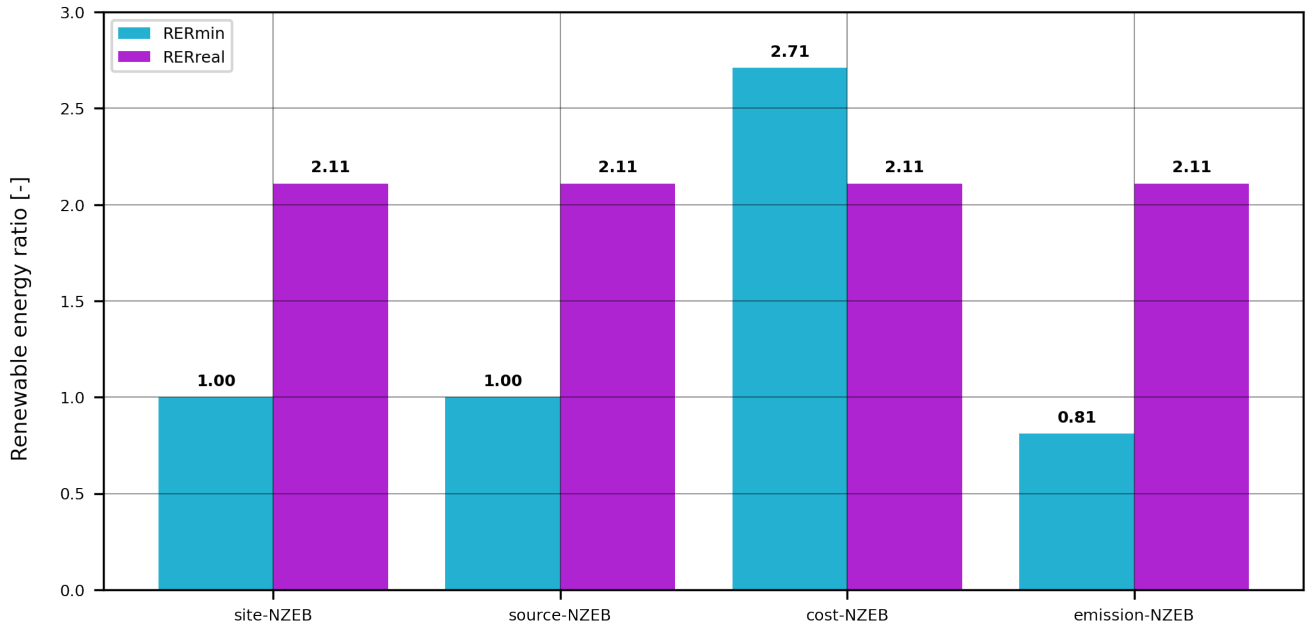


Figure 4.29: RERs comparison in the GFP-LPD scenario.

To meet site-NZEB and source-NZEB the building needs to satisfy 100% of its annual energy consumed through renewable generation. Since the building satisfies 211%, both definitions are met. The RER_{min} value of cost-NZEB is 2.72, which means that the building must satisfy almost three times its annual energy consumption with renewable energy to achieve the definition. The building has a RER_{real} of 2.11, so the definition is not met. To meet emission-NZEB the building needs to satisfy 81% of its annual energy consumed through renewable generation. Since the building satisfies 211%,the definition is met.

4.3.9 GFP-EPD: Generation on east and west façades and north parking with EPD consumption

In this scenario, renewable energy is generated through two PV systems, one located on the east and west façades and the other on the North parking of the building. In addition, it has the consumption with EPD values. The Table 4.21 shows the general result obtained from GFP-EPD scenario. It is important to clarify that all variables were calculated for an annual period.

Table 4.21: General results of GFP-EPD scenario

Variable	**Result**
E_{ec}	79.4 MWh
E_{lc}	20.4 MWh
C_{lpg}	0.1 MWh
C_{tot}	99.9 MWh
GEN_{ren}	141.1 MWh

The Figures 4.30 and 4.31 show the consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the days with the highest and lowest generation of the year, respectively.

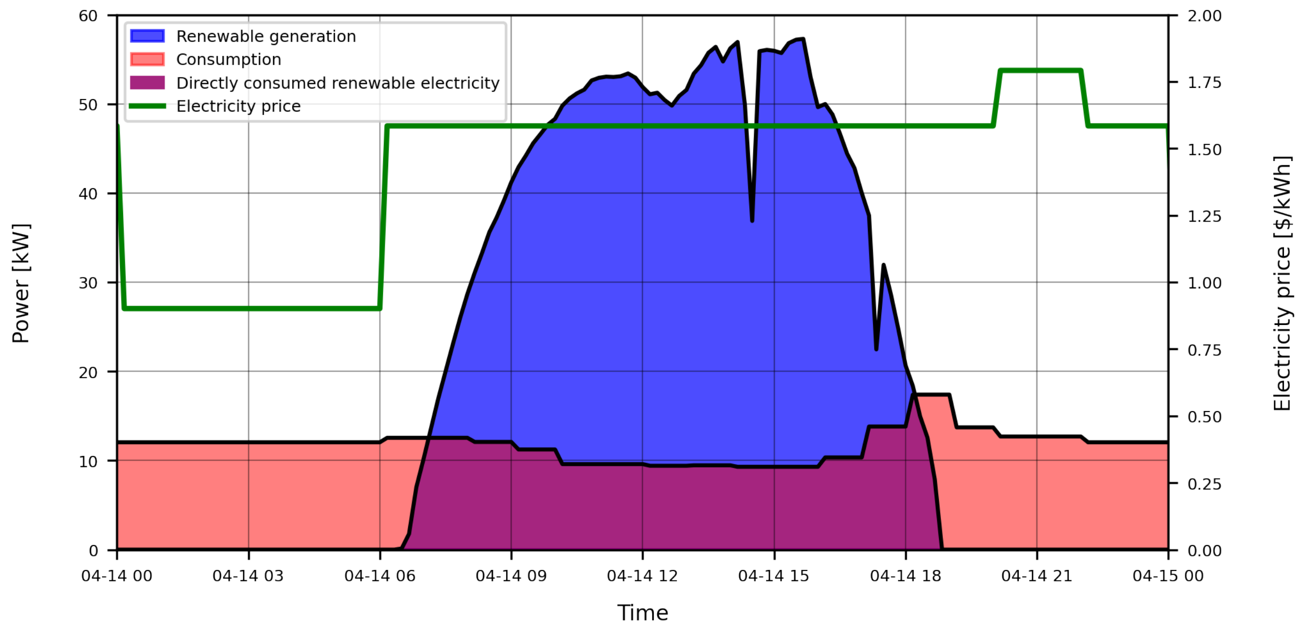


Figure 4.30: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the highest energy generated of the year for GFP-EPD scenario.

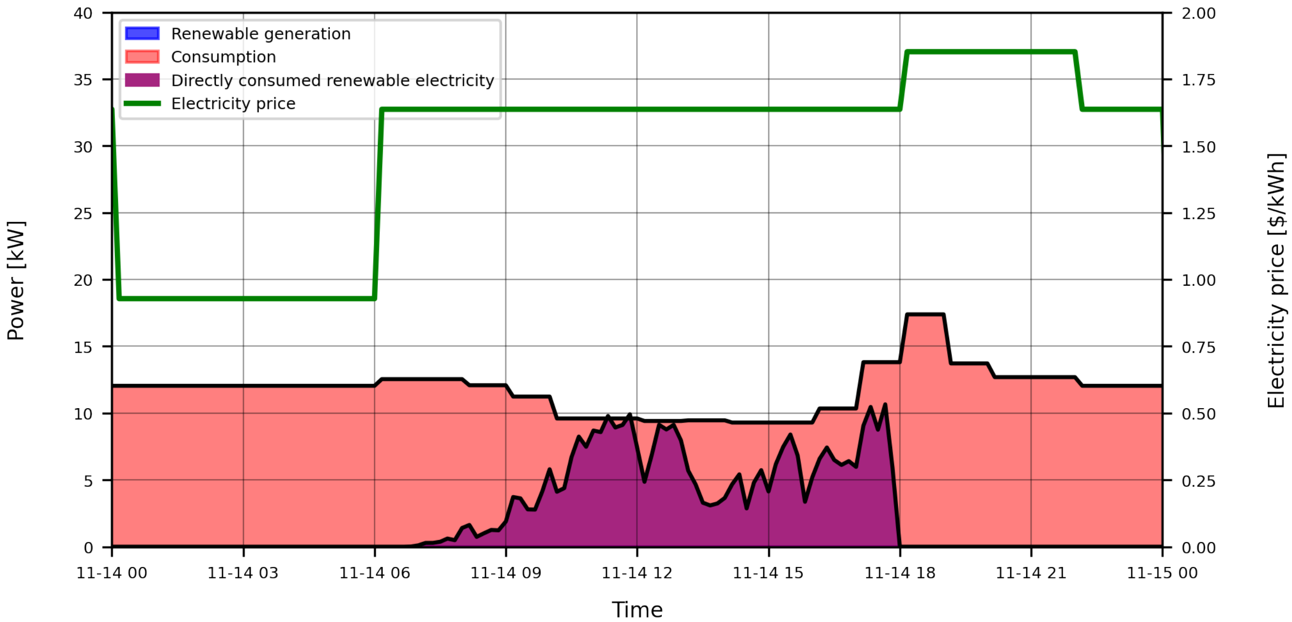


Figure 4.31: Consumption profile, renewable generation, directly consumed renewable electricity and electricity price on the working day with the lowest energy generated of the year for GFP-EPD scenario.

In this scenario, the building consumption increased due to the addition of the EPD values and the generation of both PV systems is combined. Therefore, as seen in the Figure 4.30, no shading as the sun approaches to zenith. This scenario has the largest possible renewable generation, which is produced precisely during the hours with the highest consumption at the institute, so it is also the scenario with the largest directly consumed renewable electricity. Table 4.22 shows the detailed results of the evaluation of the four NZEB definitions in this scenario.

Table 4.22: Results of the evaluation of the NZEB definitions in GFP-EPD scenario.

Definition	REN_{gen}	GEN_{ren}	$NZEB_{definition}$	**Compliance**	RER_{min}	RER_{real}
site-NZEB	99.9 MWh	141.1 MWh	-41.2 MWh	**Achieved**	1	1.41
source-NZEB	99.8 MWh	141.1 MWh	-41.3 MWh	**Achieved**	1	1.41
cost-NZEB	173.6 MWh ($259,868)	141.1 MWh ($219,636)	32.5 MWh ($40,232)	**Not achieved**	1.74	1.41
emission-NZEB	80.4 MWh	141.1 MWh	-60.7 MWh	**Achieved**	0.81	1.41

Of the four definitions evaluated, only cost-NZEB is not achieved. In this scenario GEN_{ren} continues to have the same value as in the previous one, however, $TSEU$ has an increase due to the addition of the EPD values. Therefore, a lower RER_{real} is obtained than in the previous scenario but higher than the GF-EPD and GP-EPD scenarios. The RER_{min} depends on REN_{gen} and $TSEU$. In this scenario, both REN_{gen} and $TSEU$ increase by adding the EPD values, so almost none of the RER_{min} changes with respect to the previous scenario. The only exception is with cost-NZEB and the slight increase occurs because there is now more energy imported and less exported. This scenario has the same RER_{min} value as the BF-EPD scenario because $TSEU$ and REN_{gen} do not change either. Figure 4.32 shows the RER_{min} and RER_{real} values of each evaluated definition.

REN_{gen} of cost-NZEB depends on the time at which the energy is generated. Although their generation has different shapes and quantities, the GF-EPD scenario, GP-EPD scenario and this scenario have the same REN_{gen}, since the generation of the three scenarios is between 6 AM and 6 PM, period where the price per kWh remains constant, as can be seen in Figure 4.30 and Figure 4.30. Therefore, the kWh generated in the three scenarios are worth exactly the same and their REN_{gen} is the same. Figure 4.32 shows the RER_{min} and RER_{real} values of each evaluated definition.

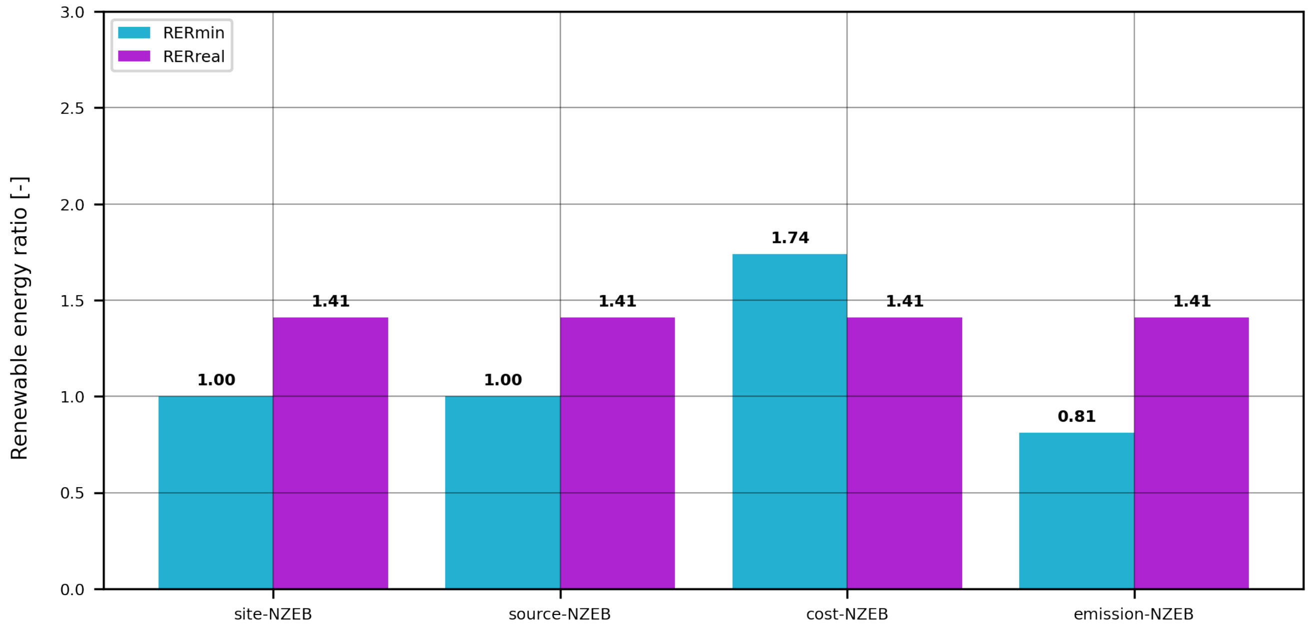


Figure 4.32: RERs comparison in the GFP-EPD scenario.

To meet site-NZEB and source-NZEB the building needs to satisfy 100% of its annual energy consumed through renewable generation. Since the building satisfies 141%, both definitions are met. The RER_{min} value of cost-NZEB is 1.74, which means that the building must satisfy almost two times its annual energy consumption with renewable energy to achieve the definition. The building has a RER_{real} of 0.89, so the definition is not met. To meet emission-NZEB the building needs to satisfy 81% of its annual energy consumed through renewable generation. Since the building satisfies 141%,the definition is met.

Chapter 5

Discussion of the results

In the last chapter, the four NZEB definitions were evaluated in the nine scenarios and the results were presented. In this chapter, a deeper analysis of the NZEB definitions is made by comparing the compliance of each one in the nine scenarios (Section 5.1). Subsequently, in Section 5.2 the final conclusions of the work are shown, where the accomplishment of the objectives set at the beginning is analysed. Finally, Section 5.3 lists the lines of research and other elements that can be developed in the future to complement and improve this work.

5.1 Analysis of one definition in all scenarios

This section analyses the meeting of a single definition in the nine scenarios. With this, it will be possible to observe the elements that make the definition be met in some scenarios and not in others.

The nine scenarios created can be divided into three categories. In the first category, energy generation is through the PV system installed on the east and west façades of the building and is composed by scenarios GF-BC (Generation on east and west façades with base case consumption), GF-LPD (Generation on east and west façades with LPD consumption) and GF-EPD (Generation on east and west façades with EPD consumption). In the second category, energy generation is through the PV system installed in the north parking lot and is composed by scenarios GP-BC (Generation on north parking with base case consumption), GP-LPD (Generation on north parking with base LPD consumption) and GP-EPD (Generation on north parking with base EPD consumption). In the third category, energy generation is through the two PV systems previously mentioned and is composed by scenarios GFP-BC (Generation on east and west façades and north parking with base case consumption), GFP-LPD (Generation on east and west façades and north parking with LPD consumption) and GFP-EPD (Generation on east and west façades and north parking with EPD consumption).

In any category, all scenarios have the same renewable generation, but the first scenario of the category is the one with the lowest consumption and the third is the one with the highest consumption. Therefore, the first scenario of the category will always be the closest to meeting all NZEB definitions and the third will always be the furthest from meeting all of them. On the other hand, doing an analysis by category, the scenarios in the third category are closest to meeting all NZEB definitions, since they have the highest renewable generation. The scenarios in the first category are furthest from meeting all of them, as they have the lowest renewable generation.

5.1.1 Analysis of site-NZEB

The Figure 5.1 compares the results of RER_{min} and RER_{real} for site-NZEB in each of the scenarios, grouped by category. The scenarios of the first category are found in the region coloured in the lightest gray, the scenarios in the second category are found in the central region, coloured in medium gray. Finally, the scenarios in the third category are in the region coloured in the darkest gray.

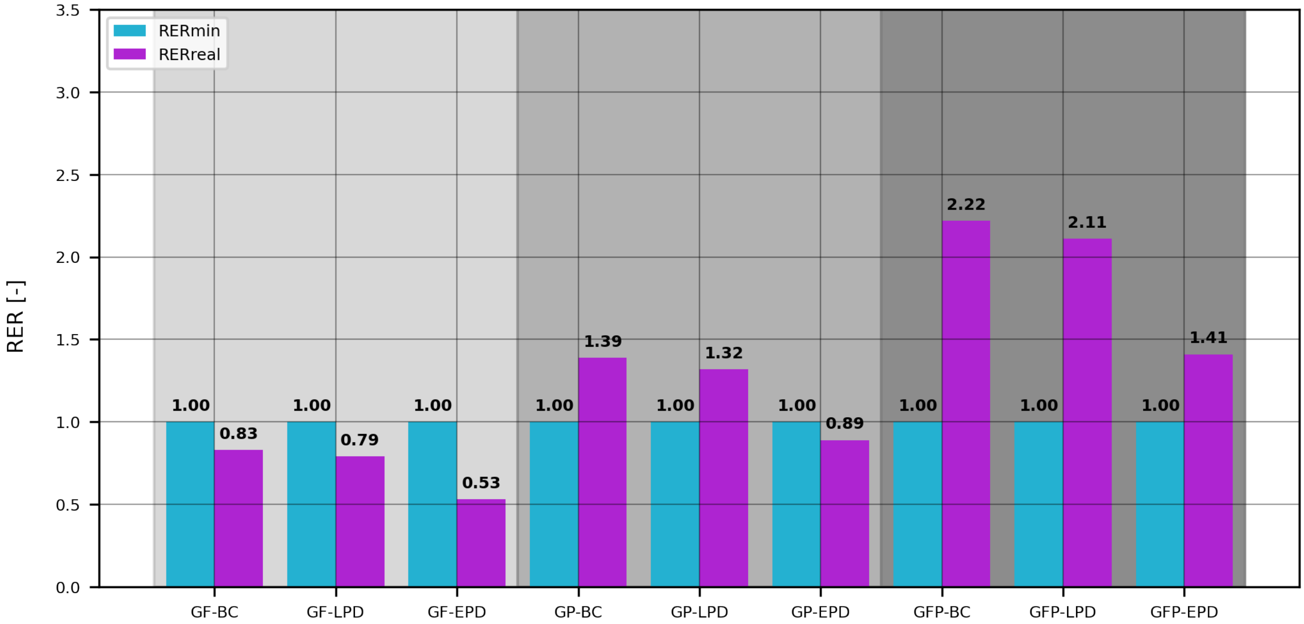


Figure 5.1: RERs comparison for site-NZEB in the nine scenarios, grouped by category.

To meet site-NZEB, a building must have an annual generation equal or greater than consumption in the same period. Therefore, the RER_{min} of the definition is always 1, which also means that the building must meet at least 100% of its annual energy consumption with renewable energy. The RER_{real} is the ratio of the annual generation with respect to the annual consumption in the building. In any category, renewable generation is the same in all scenarios, however, consumption increases when you change scenarios. Therefore, in any category, the RER_{real} decreases as the scenario changes. The scenarios that have the base case consumption will always be those with the highest RER_{real} in their category. As the category changes, renewable generation is greater and the scenario consumption remain the same. Therefore, the RER_{real} values are also higher as you change categories.

From the Figure 5.1 it can be seen that if, in a scenario, the RER_{min} and RER_{real} has the same value or RER_{real} is higher, the definition is met. In this case, it can be seen that, of the nine scenarios, site-NZEB is met in five, none of which belong to the scenarios of the first category, since these are the ones that produce less renewable energy. Of the scenarios that make up the second category, the first two meet the definition, however, the third scenario does not meet it because of the increased consumption. The scenarios in the third category are those with the highest renewable generation, so they all easily meet the definition. In conclusion, the worst scenario is the third, since its RER_{real} is the furthest from reaching the RER_{min}, while the best scenario is the seventh, since the RER_{real} exceeds the RER_{min} by far.

5.1.2 Analysis of source-NZEB

The Figure 5.2 compares the results of RER_{min} and RER_{real} for source-NZEB in each of the scenarios, grouped by category.

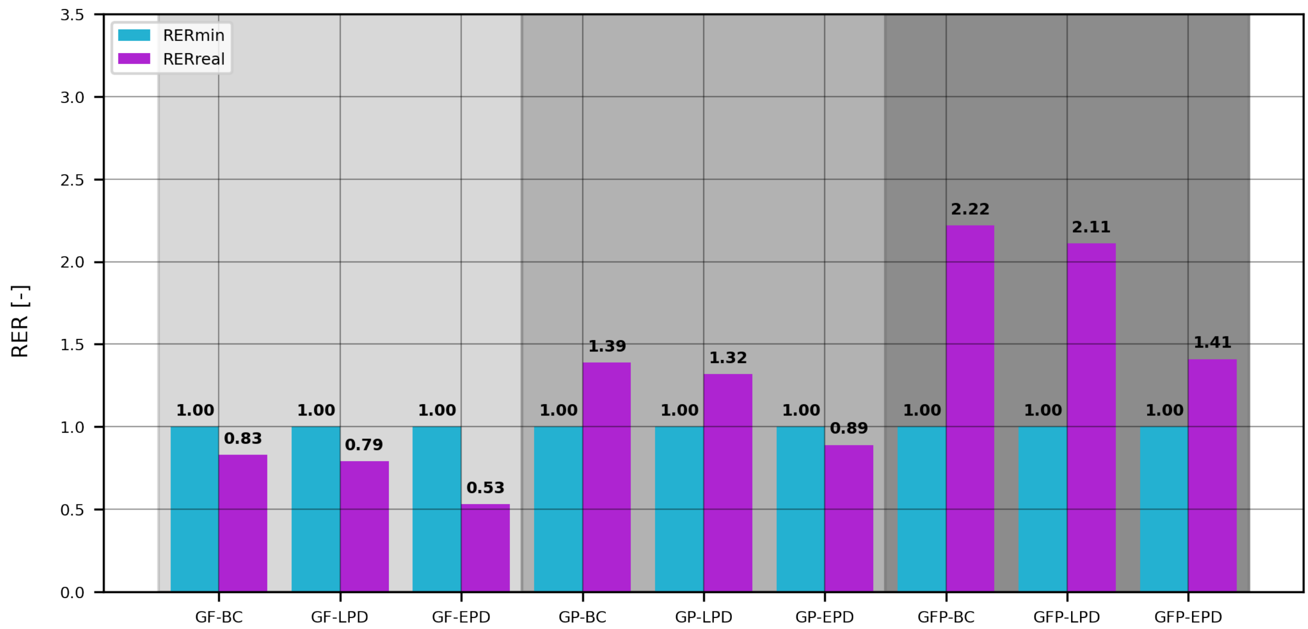


Figure 5.2: RERs comparison for source-NZEB in the nine scenarios, grouped by category.

To meet source-NZEB, the renewable energy generated in a building must also be the same as that consumed in a year, however, the difference with the previous definition is that, in this one, the energy consumed to transform all the fuels and distribute them to the building site must also be included. Once the consumption of each fuel is multiplied by its corresponding StSF, the balance is made as in the previous definition. Thus, the RER_{min} of this definition is also 1.

The most common fuels in non-residential buildings are electricity and gas, therefore it is evident that the consumption by these two sources is always part of the balances of the NZEB definitions. If the balance of site-NZEB (equation 2.1) and source-NZEB (equation 2.2) are equal to zero, the renewable energy required to meet the definition can be calculated by isolating REN_{gen} to the left side of the equation. In the case of site-NZEB, the resulting expression would be

$$REN_{gen} = ELEC + NG, \tag{5.1}$$

and in the case of source-NZEB it would be

$$REN_{gen} \times StSF_{ELEC} = (ELEC \times StSF_{ELEC}) + (NG \times StSF_{NG}). \tag{5.2}$$

In equation 5.2, the consumption of each fuel in the balance must be multiplied by its respective StSF. REN_{gen} must also be multiplied by the same $StSF_{ELEC}$, since this represents that the unit of energy generated is worth the same as the unit of energy consumed. Assuming a building that only uses electricity, $NG = 0$, then both equation 5.1 and equation 5.2 reduces to

$$REN_{gen} = ELEC. \tag{5.3}$$

Therefore, if a building only uses one energy source, the RER_{gen} is the same for both definitions. If we now assume a building with electricity and gas, then equation 5.1 and equation 5.2 must be used to calculate the RES_{gen} of site-NZEB and source-NZEB, respectively. The result would be that RER_{gen} is greater for site-NZEB than for source-NZEB. This occurs because the $StSF_{ELEC}$ is almost three times larger than the $StSF_{NG}$ (as can be seen in Table 1.2), which means that transforming and distributing electricity to the building site consumes three times more energy than gas and not as with site-NZEB where it is assumed that transforming and distributing both fuels implies the same energy consumption. For this reason, buildings that uses higher amounts of gas are closer to meeting NZEB definitions. The more gas used in a building, the greater the difference between the site-NZEB and source-NZEB balances. However, the gas consumption in the IER new building for all scenarios does not vary and is very small compared to that of electricity, so there are no noticeable differences between the site-NZEB and source-NZEB balances. For this reason, the RER_{min} and RER_{real} results shown in the Figure 5.1 look exactly the same as those in the Figure 5.2.

5.1.3 Analysis of cost-NZEB

The Figure 5.3 compares the results of RER_{min} and RER_{real} for cost-NZEB in each of the scenarios, grouped by category.

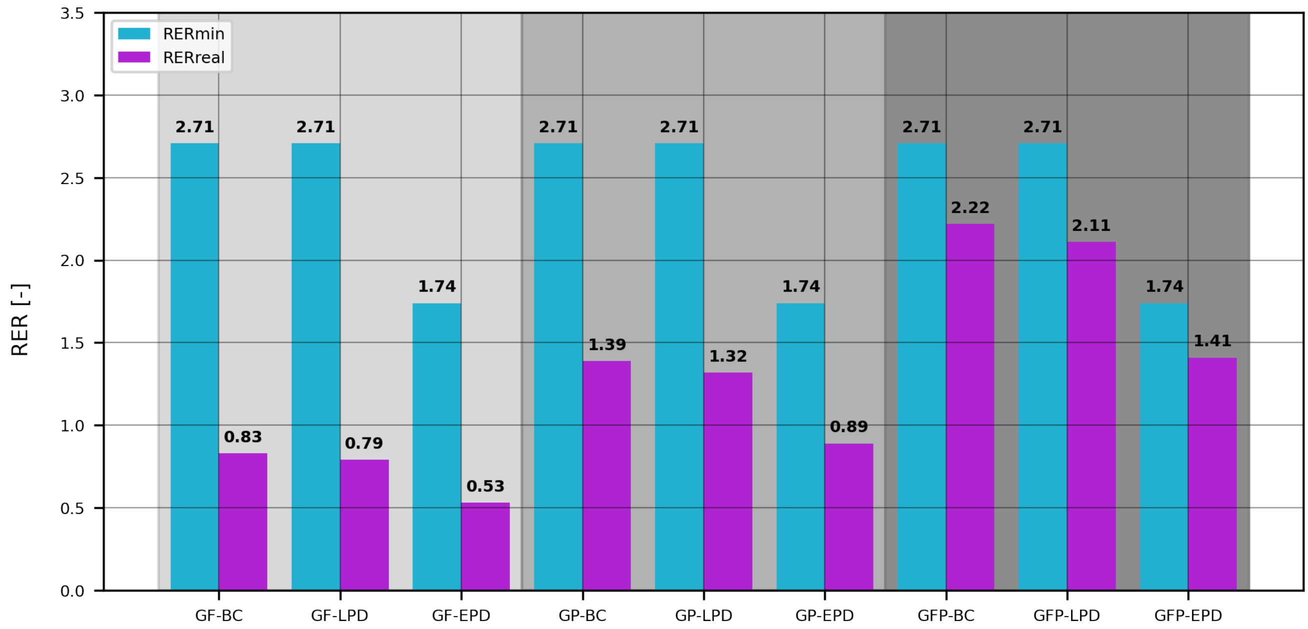


Figure 5.3: RERs comparison for cost-NZEB in the nine scenarios, grouped by category.

To meet cost-NZEB it is necessary that the money saved by the annual renewable generation is greater than or equal to the money spent by the energy consumed in a building. Unlike the balances of the other NZEB definitions, the cost-NZEB balance provides results in monetary units and not in energy units. This does not represent an obstacle to comply its function, since it evaluates if the definition is met, if utility is needed or if there is an excess.

Contrary to site-NZEB and source-NZEB, interpreting the RER_{min} of cost-NZEB is not possible just by reading the definition. According to the equation 2.7, the minimum renewable generation to meet the definition (REN_{gen}) and the total site energy use ($TSEU$) are needed to calculate RER_{min}. This last element can be calculated through the numerical model of this scenario, however, the REN_{gen} is a more complicated value to calculate.

In the site-NZEB, source-NZEB and emission-NZEB balances, the term REN_{gen} can be isolated to obtain the minimum annual renewable generation to meet the definition, however, in cost-NZEB it works differently. In the cost-NZEB balance (equation 2.3), if the price of electricity were constant throughout the year, REN_{gen} could be isolated and calculated. However, in reality, the price of electricity in Mexico varies depending on many factors, such as use of the building, state, hour, day, month and others. Therefore, to calculate the REN_{gen} it is necessary to sum all the values of $Elec_i^{Gen}$, for which a numerical method must be used. The strategy used in this work to approximate the value of REN_{gen} is to increase the renewable generation in the numerical model until the definition is met.

The RER_{min} depends on REN_{gen} and $TSEU$. RER_{min} remains constant in all categories because REN_{gen} and $TSEU$ also maintain the same value. The reason REN_{gen} is constant is because it depends on the times where the energy is generated. Although the three categories use different renewable generation options, they all have the same REN_{gen}, since generation in the three categories occurs between 6 AM and 6 PM, a period where the price per kWh remains constant. Therefore, the kWh in all categories is worth exactly the same and REN_{gen} as well.

Unlike the other two definitions, cost-NZEB is the only one whose RER_{min} values do not have a constant behaviour in a category. For example, in Figure 5.1 and Figure 5.2 it can be observed that, in a category, as the scenarios change, the RER_{min} becomes smaller. However, the RER_{min} of cost-NZEB in a category increases from 2.71 to 2.72 and then decreases to 1.74. This behaviour will be explained in steps. The slight increase from 2.71 to 2.72 occurs because there is more energy imported and less exported due to the addition of the LPD values, so you must pay a little more for this increase in imported energy. Therefore, there must be a greater REN_{gen} and a greater RER_min than in the previous scenario. The decrease from 2.72 to 1.74 is because the third scenario occupies EPD values that were calculated using the method based on consumption. The use of these EPD values flattens the consumption by equipment, so the same energy is consumed by equipment all the time, when that does not happen in reality. In Mexico there are times when electricity is more expensive and by flattening the consumption, a large part of the electricity consumed at those times is distributed to the rest of the year, which means that electricity is paid much less. Therefore, REN_{gen} decreases greatly and so does RER_{min}.

In conclusion, of the nine scenarios, none meet the definition, which is because of the large amount of renewable generation that is needed to compensate the payment for the annual energy consumed. According to the Figure 5.3, the GF-LPD scenario would be the furthest to meet the definition, however, as already mentioned before, the use of EPD values calculated by the method based on consumption is not adequate for evaluating cost-NZEB. On the other hand, it is assumed that if the LPD values had been calculated by a different method, scenario GF-EPD would surely have been the furthest away from meeting the definition. Finally, the scenario that is closest to meeting the definition is GFP-BC. Like the two previous definitions, scenarios GF-EPD and GFP-BC have been the furthest and closest to reaching the definitions, respectively. This is because GF-EPD has the highest consumption and also the lowest renewable generation, while GFP-BC has the lowest consumption and the highest renewable generation.

5.1.4 Analysis of emission-NZEB

The Figure 5.4 compares the results of RER_{min} and RER_{real} for emission-NZEB in each of the scenarios, grouped by category.

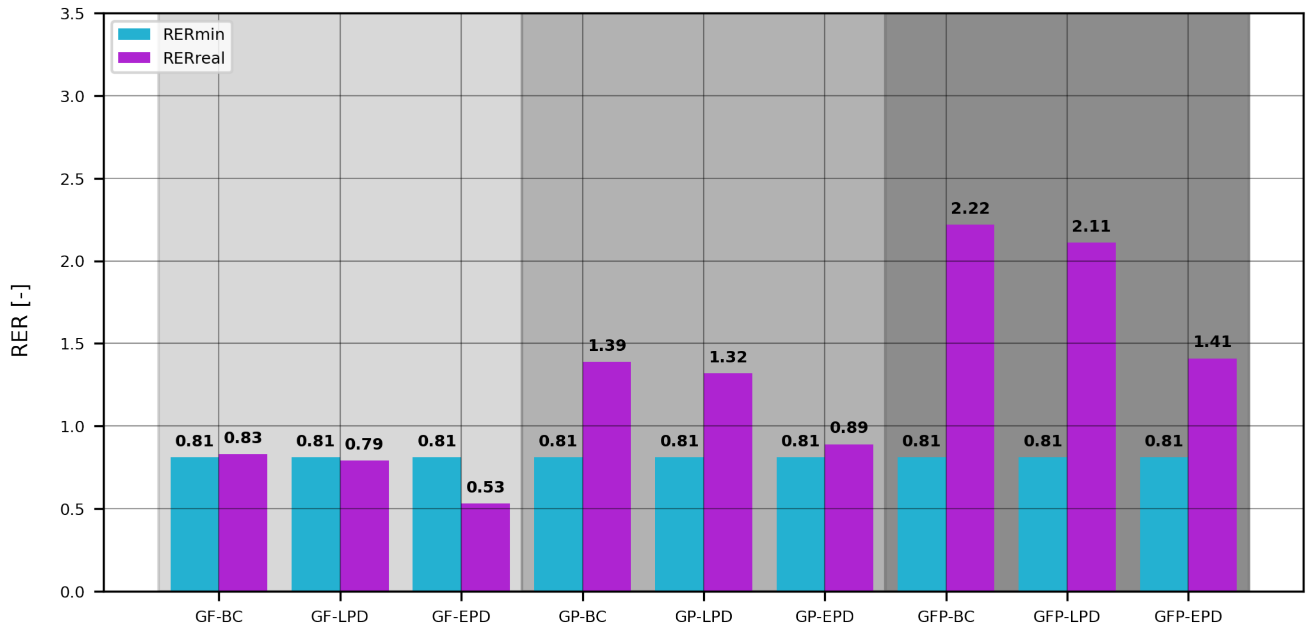


Figure 5.4: RERs comparison for emission-NZEB in the nine scenarios, grouped by category.

Finally, emission-NZEB is achieved when the emissions avoided by renewable generation are equal to or less than the emissions generated by the use of energy from the grid. According to the results obtained from the different scenarios, the RER_{min} of this definition will always be 0.81, which means that at least 81% of the building's energy consumption must be satisfied by renewable generation to meet the definition.

The RER_{min} refers to the ratio of annual minimum renewable generation that a building should have to meet an NZEB definition (REN_{gen}) with respect to its annual consumption ($TSEU$). If the balance of emission-NZEB (equation 2.4) is equal to zero, the renewable energy required to meet the definition can be calculated by isolating REN_{gen} to the left side of the equation and the resulting expression would be

$$REN_{gen} = \left(\frac{Elec \times AEF_{Elec} + NG \times EF_{NG}}{DCF \times AEF_{Elec} + (1 - DCF) \times MEF_{Elec}}\right), \tag{5.4}$$

Taking into account that $TSEU = Elec + NG$, the RER_{min} of emission-NZEB has the total consumption of the building in both the numerator and the denominator. Therefore, although one scenario has more consumption than another, the same RER_{min} for emission is maintained.

Like site-NZEB and source-NZEB the RER_{min} of this definition is also constant in all scenarios. Of the 9 scenarios, 7 are met. Among the four NZEB definitions, this is considered the easiest to achieve, since it is the one that requires the least renewable generation. It is also the only definition that is achieved in the first scenario. The only scenarios that do not meet the definition are the second and third, which is attributed to their high consumption and low renewable generation, compared to the following scenarios.

5.2 Conclusions

Because of the large participation of buildings in global energy consumption and in the energy sector emissions generation, they play a fundamental role in mitigating climate change. For many years, several countries around the world have developed research and projects whose results confirm that the way buildings are made can achieve great energy savings and environmental benefits. Mexico has not been left behind in this field and for more than two decades several projects have been carried out to build net zero energy buildings. However, most of these have been focused on the residential sector a only site-NZEB was evaluated, so to date, there is no methodology that shows the steps to follow and the necessary information to evaluate whether a commercial building meet all the NZEB definitions.

In this thesis, the concept of a net zero energy building was described, as well as its main characteristics and the information needed to work with this topic. To assess whether a building meets NZEB status, four definitions were needed: site-NZEB, source-NZEB, cost-NZEB and emission-NZEB. Even thought the new IER building was not designed to achieve NZEB, it was selected to evaluate the definitions since it has the most information available.

The construction of the numerical model was one of the most complicated activities since, despite the fact that the geometry was already built, it was necessary to collect information of all the schedules an loads of the building, as well as of renewable generation. As the new building has not entered into operation, the loads and schedules it will have are not known with certainty, so visual inspections of spaces in other buildings of the IER with similar type of use to those of the new building had to be carried out. Surveys were also carried out to collect information about energy behaviour of the occupants. With this information, assumptions were made, taking care that the results of the numerical model were as close as possible to reality.

To evaluate site-NZEB there was no problem because the information about its terms is obtained from the numerical model. However, in source-NZEB, the StSFs must be used, which are specific to the country where the building is located. Unfortunately, this information has not been developed in Mexico, so those calculated for the United States had to be used, country whose electrical system structure is very different from that of Mexico. These values should not be used for a building in Mexico, but there were no others that could be used. On the other hand, for cost-NZEB, the additional electricity costs that appear on the CFE electricity bill were used. Lastly, in emission-NZEB information is required about the marginal electricity emission factor, which is not calculated for Mexico, so once again a value from the United States had to be used. Although there are few data that could not be obtained for Mexico, they can cause large differences in the evaluation of the definitions. To design NZEBs, energy simulations are used and to make the results as close to reality as possible, it is necessary to use specific data for Mexico, so it is essential to develop research to determine the information required.

As previously mentioned, the new building is not yet operational, so it is not known if the results of the numerical model created will be similar to reality. In order to know if the energy behaviour of the modelled building is normal for one with its type of use, the energy use intensity (EUI) and power densities are used. Regarding the EUI, information has already been developed in Mexico, so it is possible to compare the value obtained from this work. The electrical power densities are divided into LPD values and EPD values, so specific values to Mexico must be found. The LPD values of ASHRAE are developed primarily for application in the United States. However, many of ASHRAE's recommendations and standards are widely recognized and used around the world as references for the design and construction of energy-efficient buildings, so its use in this work is considered adequate. In the case of the EPD values, there is no work that has developed these data for Mexico, so some from the United States had to be used.

With the information from the case study, a base case without renewable generation is created. This basic case was used as a starting point to be able to apply different consumption and renewable generation options and thus be able to create different scenarios. From the base case, the LPD and EPD values were obtained. The LPD values of this work were lower than those of ASHRAE, which is normal because they present maximum normative values. In addition, a bioclimactic design was used in the new building that allows taking advantage of natural light and the lighting system was made with efficient equipment. Regarding the EPD values, all were equal to or slightly below the values of Mahajan, however, the computer service room was the only one that far exceeded their EPD value. This occurs because, in most investigations, the consumption produced by the equipment in this space is almost never taken into account, despite the fact that it has equipment that is always in operation and has high powers, such as switches, UPS and space conditioning systems. This work recognizes the importance of this space because it is responsible for the operation of information and communication systems and because it has a great contribution to the energy consumption of the building.

The disadvantage of using EPD values is that they are calculated with the method based on consumption (review in section 1.6.1), so if they are used to calculate the equipment consumption of a space, it flattens the consumption and makes it constant for all hours of the year, which does not occur in reality. This flattening of consumption is a great disadvantage since it eliminates consumption peaks, which decreases the annual payment made for electricity. So if these EPD values are used, cost-NZEB is severely affected and its results may no longer be valid. For this reason, it is essential that information on EPD values be developed with another method and specific to Mexico.

From the base case, the annual energy consumption of the building was also obtained, which allow to calculate the EUI value of this work and compare it against the Kerdan value. They obtained an EUI of 62 kWh/m^2, while this work obtained was 31.8 kWh/m^2. The difference of 29.2 kWh/m^2 is because of the high use of LP gas in the school model and the lighting EUI in the study of Kerdan et al. [2015]. The bioclimatic design of the building allows it to take advantage of daylight and save energy, in addition to the fact that the lighting equipment installed is very efficient.

Nine scenarios were created with the two renewable generation options and three consumption options: the base case consumption, the consumption with the LPD values and the consumption with the EPD values. In each of the scenarios, the four definitions were evaluated. Of the nine scenarios, the second and third did not meet any definition, which is attributed to high consumption for using the power densities and to low renewable generation of the system installed on the east and west façades. On the contrary, there was no scenario that met all the definitions, however, the one that was closest to achieving it was the seventh, which is attributed to low consumption for not using power densities and also to high renewable generation that the two PV systems have when they work together.

If the new IER building wanted to meet site-NZEB, the renewable energy produced by the façade systems would not be enough. However, it could be met only with the north parking system. Since the amount of LP-Gas consumed in the building is very small compared to the electrical consumption, the source-NZEB results are almost the same as site-NZEB, so if one is achieved, the other will to. Because of the great amount of renewable generation needed, cost-NZEB is consider the most difficult definition to meet. If the new IER building wanted to meet cost-NZEB, it would have to generate more renewable energy, because even with the two PV systems working together, it could not be achieved. Finally, if the new IER building wanted to meet at least one NZEB definition, emission-NZEB would be the easiest to achieve and would only require the PV system installed on the east and west façades.

Although the new IER building was not designed to be NZEB, it does have the characteristics of one. Its bioclimatic design, the implemented energy efficiency measures and the planned renewable generation options allow the building to meet three of the four NZEB definitions, which is considered very good for a building that did not even have this objective. According to the results of this work, when the building comes into operation and PV systems are installed it can be considered a NZEB.

The hardest part of this work was not understanding the definitions, but collecting all the data to evaluate them. When you want to assess compliance with the NZEB definitions in a building that is not yet built or is not in operation, it is necessary to make an energy simulation to estimate the consumption and generation of the building. Obtaining the results of these two variables is complicated if there is no information on the electrical loads of the building and the schedules. For this work, because of the resource availability, a rudimentary collection of these data had to be done, but in the future there will be more people trying to make NZEBs in Mexico and it is necessary that, by then, there is already a database with all the information required to evaluate the definitions and also the methodology that must be followed in the case of non-residential buildings. The government of each country, as well as its academic institutions, should begin to develop research to create a database with all the information available to adequately simulate any kind of buildings in Mexico, only then we can make the buildings part of the fight against climate change.

5.3 Future work

Below is a list of lines of research or elements that could be developed in the future to complement and improve the results of this work:

- **Calculation of the site to source factors for Mexico:** source-NZEB considers in its calculation the energy losses that exist for the transformation and distribution of fuels to the site. It does this by multiplying the consumption of each fuel by its respective site to source factor ($StSF$), which are specific to each country and are calculated with data from the electrical system. For the United States and Canada, the EnergyStar company is in charge of calculating these values for different fuels. In the case of Mexico, there is no investigation of the $StSFs$, but it is probable that it can be carried out with data from the national energy balance.

- **Additional electricity cost in Mexico:** These costs are essential to calculate the balance of cost-NZEB, however, there is not a very clear idea of what these costs might be in Mexico.

- **Include the cost of PV systems in the cost-NZEB balance:** Some authors point out that, for the cost-NZEB to be more complete, it is necessary to include the cost of the installed renewable systems. This decision depends on the objectives of the owner of the building. It is evident that contemplating the cost of these systems can complicate the calculation of the definition and also its analysis, since aspects such as net present value and the internal rate of return could be included.

- **Emission factors:** In the emission balance-NZEB there are several emission factors required. Mexico has information about the emission factor for electricity and the emission factor for LP gas, however, these data are from more than twenty years ago, so it would be advisable to obtain more updated data. On the other hand, Mexico does not have information about the marginal factor of electricity, which is also necessary for the calculation of the definition.

- **Projections of NZEB definitions:** The balance of all definitions is made up of variables that can change over time. Building consumption and renewable generation are data that can change over the years because of many factors (changes in technology, schedules and occupancy, loss of efficiency in the modules and others). In addition to this, StSF, electricity prices, and emission factors can also change a lot over time. For this reason, it is advisable to make projections where all these changes are taken into account and compliance with the definitions is analysed, so that strategies are ready to be implemented.

- **Equipment power density:** One of the reasons why cost-NZEB could not be correctly evaluated in the scenarios with EPD values, is because they flatten the consumption for equipment, therefore consumption peaks are suppressed and the result of the definition is affected. EDP values must be calculated with a method that does not flatten the consumption and that are specific to Mexico for academic buildings.

- **Ventilation and thermal comfort:** When designing a building, the thermal comfort of the occupants must always be one of the priorities. If a correct bioclimatic design is implemented, the occupants could be in comfort without having to turn on the air conditioning systems that consume a lot of energy or at least could use these systems much less. To obtain information on the thermal comfort of the occupants, information is required on the physical variables of the environment and the person, as well as adding ventilation in the simulation. All this information must be analysed before being added to the simulation. Despite not being considered in this work, it may be supplemented in the future.

- **Database for building simulation:** To make numerical simulations of non-residential buildings, a lot of information needs to be collected about all loads, occupancies and schedules. One way to facilitate this activity is by creating a database with all this information, which can be accessed by all the people who are making an energy simulation of a building with a similar type of use.

Appendix A

Data acquisition for electrical loads

This appendix describes the methodology to estimate the amount of equipments per space, the connection time and the connection schedules of some electrical equipment. It is important to remember that connection time refers to the time that equipment in a space remains connected to the building's electrical grid during a period. This methodology only apply to all the electrical equipment whose amount per space and connection time is more complicated to estimate because of the different use that is given to them on every weekday and in the different spaces.

A.1 Electrical equipment surveys

To calculate the annual consumption of these equipments, it is necessary to collect information about the energy behaviour of the users, which changes depending on the weekday. With this objective, a survey was carried out on a sample of 22 students from different generations of IER bachelor. Because this information is also required for laboratory equipment, a sample of 5 professors in charge of the IER laboratories was also carried out.

Electrical equipments survey (Spanish version)

- Consumo eléctrico IER - Estudiantes de licenciatura (semestre 2023-2)

1. ¿A qué generación perteneces?
   9G, 10G , 11G, 12G
2. ¿Cuántas horas conectas tu computadora al tomacorrientes los lunes?
   Rango de 1 a 10 horas
3. ¿Cuántas horas conectas tu computadora al tomacorrientes los martes?
   Rango de 1 a 10 horas
4. ¿Cuántas horas conectas tu computadora al tomacorrientes los miércoles?
   Rango de 1 a 10 horas
5. ¿Cuántas horas conectas tu computadora al tomacorrientes los jueves?
   Rango de 1 a 10 horas
6. ¿Cuántas horas conectas tu computadora al tomacorrientes los viernes?
   Rango de 1 a 10 horas
7. ¿Cuántas horas se utiliza el proyector en tus clases del lunes?
   Rango de 1 a 10 horas
8. ¿Cuántas horas se utiliza el proyector en tus clases del martes?
   Rango de 1 a 10 horas
9. ¿Cuántas horas se utiliza el proyector en tus clases del miércoles?
   Rango de 1 a 10 horas

10. ¿Cuántas horas se utiliza el proyector en tus clases del jueves?
Rango de 1 a 10 horas

11. ¿Cuántas horas se utiliza el proyector en tus clases del viernes?
Rango de 1 a 10 horas

12. En promedio, ¿cuántas horas al día conectas tu celular al tomacorrientes?
Rango de 1 a 10 horas

13. En promedio, ¿cuántas horas al día se utiliza la TV en tus clases?
Rango de 1 a 10 horas

14. Después de que terminan tus clases del día, ¿te retiras del instituto o te quedas a seguir trabajando?
Me retiro del instituto, Me quedo a seguir trabajando

15. Si te quedas en el instituto a seguir trabjando, ¿hasta qué hora te retiras? Si no aparece la hora, escríbela en la casilla "Otras.
No me quedo en el instituto a trabajar, 6 pm, 7 pm, 8 pm, 9 pm, 10 pm, Otras

- Consumo eléctrico IER - Laboratorios de licenciatura (semestre 2023-2)

1. En promedio, ¿cuánto tiempo por semana se utilizan los extractores en las clases de laboratorio?
Respuesta abierta

2. ¿Cuáles son los equipos eléctricos de laboratorio que se utilizan en las clases y cuánto tiempo se utilizan por semana? En el siguiente ejemplo se muestra la manera correcta para responder: Microoscopio - 6 horas. Autoclave - 5 horas.
Respuesta abierta

Electrical equipments survey (English version)

- Electricity consumption IER - Bachelor students (semester 2023-2)

1. What generation do you belong to?
9G, 10G, 11G, 12G

2. How many hours do you connect your computer to the electrical outlet on Mondays?
Range from 1 to 10 hours

3. How many hours do you connect your computer to the outlet on Tuesdays?
Range from 1 to 10 hours

4. How many hours do you connect your computer to the electrical outlet on Wednesdays?
Range from 1 to 10 hours

5. How many hours do you connect your computer to the outlet on Thursdays?
Range from 1 to 10 hours

6. How many hours do you connect your computer to the electrical outlet on Fridays?
Range from 1 to 10 hours

7. How many hours is the projector used in your Monday classes?
Range from 1 to 10 hours

8. How many hours is the projector used in your Tuesday classes?
Range from 1 to 10 hours

9. How many hours is the projector used in your Wednesday classes?
Range from 1 to 10 hours

10. How many hours is the projector used in your Thursday classes?
Range from 1 to 10 hours

11. How many hours is the projector used in your Friday classes?
    Range from 1 to 10 hours

12. On average, how many hours a day do you connect your cell phone to the electrical outlet?
    Range from 1 to 10 hours

13. On average, how many hours a day do you use the TV in your classes?
    Range from 1 to 10 hours

14. After you finish your classes for the day, do you leave the institute or do you stay to continue working?
    I leave the institute, I stay to continue working

15. If you stay at the institute to continue working, until what time do you retire? If the time does not appear, write it in the "Others" box.
    I don't stay at the institute to work, 6 pm, 7 pm, 8 pm, 9 pm, 10 pm, Others

- Electricity consumption IER - Bachelor laboratories (semester 2023-2)

1. On average, how much time per week are exhaust fans used in laboratory classes?
   Open answer

2. What electrical laboratory equipment is used in the classes and how much time is it used per week? The following example shows the correct way to respond: Microscope - 6 hours. Autoclave - 5 hours.
   Open answer

A.2 Methodology

In total there are six electrical equipment of which we want to know their amounts per space, the connection time and the connection schedules. These equipment are the following:

- Computer
- Cell phone
- Projector
- TV
- Exhaust fan
- Laboratory equipment

To obtain the required information from these equipments, it is necessary for them to be divided into two groups. The first group is made up of computers and cell phones, while the second group is made up of projectors, televisions, exhaust fan, and laboratory equipment. In the first group are those equipment that all people own individually. On the other hand, in the second group are those equipment that are usually installed in the space and used in a communal way. Therefore, it is common to found fewer units per space in the second group than in the first.

Given the distinct characteristics of two team groups, separate methodologies are required. The following subsections describe the methodologies employed to calculate group-specific information, including the corresponding results. It is assumed that survey data has been previously gathered.

A.2.1 First group equipment

Since the electrical equipment that are in first group are computers and cell phones, from the question 2 to 6 of the bachelor students survey, an average of the time that a student connects her/his computer on each weekday is obtained. Subsequently, with question 12, an average of the time that a student connects her/his cell phone on any given weekday is obtained. The results are listed below:

Computers

- Monday = 2.66 h
- Tuesday = 2.38 h
- Wednesday = 3.28 h
- Thursday = 3.28
- Friday = 2.04 h

Cellphones

- Any weekday = 2.04 h

These results are multiplied by the daily occupancy of students and teachers of the building (164 people) and the total connection time of computers and cell phones is obtained for each weekday.

Computers

- Monday = 436.24 hours
- Tuesday = 390.32 hours
- Wednesday = 537.92 hours
- Thursday = 459.2 hours
- Friday = 334.56 hours

Cellphones

- Any weekday = 334.56 h

To distribute these connection times in all the spaces of the building for each weekday, the following criteria are taken into account:

1. **Spaces where students spend the most time:** The first criterion is to give more connection time to the spaces where students spend more time while they are in the institute. For example, if in one day, students spend 50% of the time in classrooms (in class), 50% of the hours that they connect computers or cell phones in that specific day, will account for the classrooms (in class).

   To obtain the percentage of time that students spend in each of the spaces, the following assumptions are made. Bachelor students usually have assigned base classrooms where they spend most of their time. For the study case, F1Cr411, F1Cr412, F1Cr413 and F1Cr414 are assumed as base classrooms, since they are the ones with the highest occupancy and because they are four, as the number of bachelor groups. Students in a base classroom have approximately 12 hours (8 am – 8 pm) to connect their equipment in different spaces of the new building. If there are four base classroom and each one has 12 available hours, there is a total of 48 hours where their equipment can be connected. In this period, there are connection hours in different space types: in classrooms (in class or in free hours), in laboratories, in the computer room and in the work rooms. The 48 hours represent 100% of the time that is available for the students of the four base classrooms to connect their equipments, then the percentage of time that students spend in the spaces types for each weekday is found in the Table A.1.

Table A.1: Percentage of time that students spend in the space types for each weekday.

	Monday		Tuesday		Wednesday		Thursday		Friday	
	h	**%**	**h**	**%**	**h**	**%**	**h**	**%**	**h**	**%**
Classroom (in class)	30	62.5	29	60.4	16	33.3	29	60.4	8	16.7
Classroom (free hours)	14	29.2	7	14.6	20	41.7	7	14.6	32	66.7
Laboratory	0	0	4	8.3	6	12.5	6	12.5	4	8.3
Computer room	0	0	4	8.3	2	4.2	2	4.2	0	0
Work room	4	8.3	4	8.3	4	8.3	4	8.3	4	8.3
Total	48	100	48	100	48	100	48	100	48	100

Therefore, the total connection time of each weekday is multiplied by the percentages of time in each space type and the results are shown in the Tables A.2 and A.3. In the computer room, there is already a fixed amount of computers in the space and computer connection time, so this space type is not taken into account for the distribution of computer connection time.

Table A.2: Computers connection time in each space type, by weekday.

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Space types	**Computers connection time (h)**				
Classroom (in class)	272.7	235.8	179.3	277.4	55.8
Classroom (free hours)	127.2	56.9	224.1	67	223
Laboratory	0	32.5	67.2	57.4	27.9
Work room	36.4	32.5	44.8	38.3	27.9

Table A.3: Cell phones connection time in each space type, by weekday.

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Space types	**Cell phones connection time (h)**				
Classroom (in class)	209.1	202.1	115.5	202.1	55.8
Classroom (free hours)	97.6	48.8	139.4	48.8	223
Laboratory	0	27.9	41.8	41.8	27.9
Computer room	0	27.9	13.9	13.9	0
Work room	27.9	27.9	27.9	27.9	27.9

2. **Occupancy of the spaces:** Each space type shown in the Table A.1 is made up of different spaces with different occupancy. For example, the Classrooms (in class) are made up of 10 different spaces (as can be seen in the Figure 3.1) and while the four bachelor base classrooms have a maximum occupancy of 41 people, the others have occupancies of 11 people and 21 people. Therefore, the second distribution criterion is that, once the connection time has been distributed in the space types where the students spend more time, now the resulting connection times must distributed in the spaces with more occupancy. This is considered a good assumption because in reality it is common to see more equipment connected in spaces with more people. The Figures A.4 to A.8 shows the computers connection time distributed with the second criterion for each weekday. On the other hand, from Table A.9 to A.13 the same information is shown but for cell phones. Due to the difficulty in calculating the amount of connected equipment, the connection time and the connection schedule in a class, a constant number of equipment that remains connected throughout the class is calculated. The result is found in the final column of all these tables. Therefore, the normal class schedule is assumed as the connection schedule (column 3) and the duration of the class is assumed as the connection time (column 4).

Table A.4: Distribution of computers connection time according with second criterion on Monday.

Monday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Percentage of total occupancy [%]**	**Computers connection time [h]**	**Computers connected in class (no rounding)**	**Computers connected in class (rounding)**
	F1Cr411	8 am – 2 pm	6	41	16.4	44.7	7.5	7
	F1Cr412	8 am – 2 pm	6	41	16.4	44.7	7.5	7
	F1Cr413	12 pm – 2 pm	2	41	16.4	44.7	22.4	22
	F1Cr414	8 am – 12 pm	4	41	16.4	44.7	11.2	11
	F2Cr111	12 pm – 2 pm	2	11	4.4	12	6	6
Classroom (in class)	F2Cr111	4 pm – 6 pm	2	11	4.4	12	6	6
	F2Cr112	12 pm – 2 pm	2	11	4.4	12	6	6
	F2Cr112	4 pm – 6 pm	2	11	4.4	12	6	6
	F2Cr211	12 pm – 2 pm	2	21	8.4	22.9	11.5	11
	F2Cr211	4 pm – 6 pm	2	21	8.4	22.9	11.5	11
	Total	-	**30**	**250**	**100**	**272.7**	**95.3**	**93**
	F1Cl411	2 pm - 6 pm	4	20	20	25.4	6.4	6
	F1Cr412	2 pm - 4 pm	2	20	20	25.4	12.7	13
Classroom (free hours)	F1Cr413	8 am - 12 pm	4	20	20	25.4	6.4	6
	F1Cr413	2 pm - 4 pm	2	20	20	25.4	12.7	13
	F1Cr414	2 pm - 4 pm	2	20	20	25.4	12.7	13
	Total	-	**14**	**100**	**100**	**127.2**	**50.9**	**51**
	F1Lab	-	0	0	0	0	0	0
Laboratory	F2Lab1	-	0	0	0	0	0	0
	F2Lab2	-	0	0	0	0	0	0
	Total	-	0	0	0	0	0	0
	F0Work	6 pm – 8 pm	2	40	50	18.2	9.1	9
Work room	F2Work	6 pm – 8 pm	2	40	50	18.2	9.1	9
	Total	-	**4**	**80**	**100**	**36.4**	**18.2**	**18**

To determine the percentage of total occupancy (column 6), we start by using the total occupancy of the space type as a reference. We calculate how much each individual space contributes to this total occupancy in percentage terms. Then, we apply these percentages to the computers connection time shown in Table A.2 to obtain the computers connection time in each space (column 7). In this step it is essential to verify that the correct space types, equipment and weekday are being used. To obtain the amount of computer connected (column 8) that will constantly be connected during a class , we divide the computers connection time (column 7) over the connection time (column 4). In the last column (column 9), we round the results from the previous column, as it is not possible to have fractional equipment units. This process applies in the same way from table A.4 to A.13.

Table A.5: Distribution of computers connection time according with second criterion on Tuesday.

				Tuesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Percentage of total occupancy [%]**	**Computers connection time [h]**	**Computers connected in class (no rounding)**	**Computers connected in class (rounding)**
	F1Cr411	8 am – 10 pm	2	41	14.6	34.5	17.3	17
	F1Cr411	4 pm – 6 pm	2	41	14.6	34.5	17.3	17
	F1Cr412	8 am – 2 pm	6	41	14.6	34.5	5.8	6
	F1Cr413	12 pm – 2 pm	2	41	14.6	34.5	17.3	17
	F1Cr414	8 am – 12 pm	4	41	14.6	34.5	8.6	9
Classroom (in class)	F2Cr111	12 pm – 2 pm	2	11	3.9	9.3	4.6	5
	F2Cr112	10 am – 12 pm	2	11	3.9	9.3	4.6	5
	F2Cr113	10 am – 2 pm	4	11	3.9	9.3	2.3	2
	F2Cr212	8 am – 11 am	3	21	7.5	17.7	5.9	6
	F2Cr213	8 am – 10 am	2	21	7.5	17.7	8.8	9
	Total	-	**29**	**280**	**100**	**235.8**	**92.5**	**93**
	F1Cr411	2 pm - 4 pm	4	20	25	14.2	3.6	4
	F1Cr412	2 pm - 4 pm	2	20	25	14.2	7.1	7
Classroom (free hours)	F1Cr413	2 pm - 4 pm	4	20	25	14.2	3.6	4
	F1Cr413	2 pm - 3 pm	2	20	25	14.2	7.1	7
	Total	-	**12**	**80**	**100**	**56.9**	**21.3**	**22**
	F1Lab	4 pm - 6 pm	2	21	50	16.3	8.1	8
Laboratory	F2Lab2	4 pm - 6 pm	2	21	50	16.3	8.1	8
	Total	-	**4**	**42**	**100**	**32.5**	**16.3**	**16**
	F0Work	6 pm – 8 pm	2	40	50	16.3	8.1	8
Work room	F2Work	6 pm – 8 pm	2	40	50	16.3	8.1	8
	Total	-	**4**	**80**	**100**	**32.5**	**16.3**	**16**

Table A.6: Distribution of computers connection time according with second criterion on Wednesday.

Wednesday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Percentage of total occupancy [%]**	**Computers connection time [h]**	**Computers connected in class (no rounding)**	**Computers connected in class (rounding)**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	41	26.5	47.4	7.9	8
	F1Cr413	12 pm – 2 pm	2	41	26.5	47.4	23.7	24
	F1Cr414	8 am – 12 pm	4	41	26.5	47.4	11.9	12
	F2Cr112	12 pm – 2 pm	2	11	7.1	12.7	6.4	6
	F2Cr211	12 pm – 2 pm	2	21	13.5	24.3	12.1	12
	Total	-	**16**	**155**	**100**	**179.3**	**62**	**62**
Classroom (free hours)	F1Cr411	2 pm - 6 pm	4	20	25	56	14	14
	F1Cr412	8 am - 6 pm	10	20	25	56	5.6	6
	F1Cr413	2 pm - 4 pm	2	20	25	56	28	28
	F1Cr414	2 pm - 6 pm	4	20	25	56	14	14
	Total	-	**20**	**80**	**100**	**224.1**	**61.6**	**62**
Laboratory	F1Lab	8 am – 2 pm	6	21	100	67.2	11.2	11
	Total	-	**6**	**21**	**100**	**67.2**	**11.2**	**11**
Work room	F0Work	6 pm – 8 pm	2	40	50	22.4	11.2	11
	F2Work	6 pm – 8 pm	2	40	50	22.4	11.2	11
	Total	-	**4**	**80**	**100**	**44.8**	**22.4**	**22**

Table A.7: Distribution of computers connection time according with second criterion on Thursday.

Thursday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Percentage of total occupancy [%]**	**Computers connection time [h]**	**Computers connected in class (no rounding)**	**Computers connected in class (rounding)**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	41	13.2	36.7	6.1	6
	F1Cr411	4 pm – 6 pm	2	41	13.2	36.7	18.3	18
	F1Cr412	8 am – 12 pm	4	41	13.2	36.7	9.2	9
	F1Cr413	12 pm – 2 pm	2	41	13.2	36.7	18.3	18
	F1Cr414	12 pm – 2 pm	2	41	13.2	36.7	18.3	18
	F1Cr414	4 pm – 6 pm	2	41	13.2	36.7	18.3	18
	F2Cr112	10 am – 12 pm	2	11	3.5	9.8	4.9	5
	F2Cr113	10 am – 2 pm	4	11	3.5	9.8	2.5	2
	F2Cr212	8 am – 11 am	3	21	6.8	18.8	6.3	6
	F2Cr213	8 am – 10 am	2	21	6.8	18.8	9.4	9
	Total	-	**29**	**310**	**100**	**277.4**	**111.7**	**109**
Classroom (free hours)	F1Cr411	2 pm - 4 pm	2	20	25	16.7	8.4	8
	F1Cr412	2 pm - 3 pm	1	20	25	16.7	16.7	17
	F1Cr413	2 pm - 4 pm	2	20	25	16.7	8.4	8
	F1Cr414	2 pm - 4 pm	2	20	25	16.7	8.4	8
	Total	-	**7**	**80**	**100**	**67**	**41.9**	**41**
Laboratory	F1Lab	12 pm - 2 pm	2	21	33.3	19.1	9.6	10
	F1Lab	4 pm - 6 pm	2	21	33.3	19.1	9.6	10
	F2Lab2	4 pm - 6 pm	2	21	33.3	19.1	9.6	10
	Total	-	**6**	**63**	**100**	**57.4**	**28.7**	**30**
Work room	F0Work	6 pm – 8 pm	2	40	50	19.1	9.6	10
	F2Work	6 pm – 8 pm	2	40	50	19.1	9.6	10
	Total	-	**4**	**80**	**100**	**38.3**	**19.1**	**20**

Table A.8: Distribution of computers connection time according with second criterion on Friday.

Friday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Percentage of total occupancy [%]**	**Computers connection time [h]**	**Computers connected in class (no rounding)**	**Computers connected in class (rounding)**
Classroom (in class)	F1Cr412	8 am – 2 pm	6	41	66.1	36.9	6.1	6
	F2Cr211	8 am – 10 am	2	21	33.9	18.9	9.4	9
	Total	-	**8**	**62**	**100**	**55.8**	**15.6**	**15**
Classroom (free hours)	F1Cr411	8 am - 6 pm	10	20	25	55.8	5.6	6
	F1Cr412	2 pm - 4 pm	2	20	25	55.8	27.9	28
	F1Cr413	8 am - 6 pm	10	20	25	55.8	5.6	6
	F1Cr414	8 am - 6 pm	10	20	25	55.8	5.6	6
	Total	-	**32**	**80**	**100**	**223**	**44.6**	**46**
Laboratory	F2Lab1	8 am - 12 pm	4	21	100	27.9	7	7
	Total	-	**4**	**21**	**100**	**27.9**	**7**	**7**
Work room	F0Work	6 pm – 8 pm	2	40	50	13.9	7	7
	F2Work	6 pm – 8 pm	2	40	50	13.9	7	7
	Total	-	**4**	**80**	**100**	**27.9**	**13.9**	**14**

Table A.9: Distribution of cell phones connection time according with second criterion on Monday.

Monday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Percentage of the total occupancy [%]**	**Cell phones connection time [h]**	**Cell phones connected in the class (no rounding)**	**Cell phones connected in class (rounding)**
	F1Cr411	8 am – 2 pm	6	41	16.4	34.3	5.7	6
	F1Cr412	8 am – 2 pm	6	41	16.4	34.3	5.7	6
	F1Cr413	12 pm – 2 pm	2	41	16.4	34.3	17.1	17
	F1Cr414	8 am – 12 pm	4	41	16.4	34.3	8.6	9
	F2Cr111	12 pm – 2 pm	2	11	4.4	9.2	4.6	5
Classroom (in class)	F2Cr111	4 pm – 6 pm	2	11	4.4	9.2	4.6	5
	F2Cr112	12 pm – 2 pm	2	11	4.4	9.2	4.6	5
	F2Cr112	4 pm – 6 pm	2	11	4.4	9.2	4.6	5
	F2Cr211	12 pm – 2 pm	2	21	8.4	17.6	8.8	9
	F2Cr211	4 pm – 6 pm	2	21	8.4	17.6	8.8	9
	Total	-	**30**	**250**	**100**	**209.1**	**73.1**	**76**
	F1Cr411	2 pm - 6 pm	4	20	20	19.5	4.9	5
	F1Cr412	2 pm - 4 pm	2	20	20	19.5	9.8	10
Classroom (free hours)	F1Cr413	8 am - 12 pm	4	20	20	19.5	4.9	5
	F1Cr413	2 pm - 4 pm	2	20	20	19.5	9.8	10
	F1Cr414	2 pm - 4 pm	2	20	20	19.5	9.8	10
	Total	-	**14**	**100**	**100**	**97.6**	**39**	**40**
	F0Work	6 pm – 8 pm	2	40	50	13.9	7	7
Work room	F2Work	6 pm – 8 pm	2	40	50	13.9	7	7
	Total	-	**4**	**80**	**100**	**27.9**	**13.9**	**14**

Table A.10: Distribution of cell phones connection time according with second criterion on Tuesday.

Tuesday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Percentage of the total occupancy [%]**	**Cell phones connection time [h]**	**Cell phones connected in the class (no rounding)**	**Cell phones connected in class (rounding)**
	F1Cr411	8 am – 10 pm	2	41	14.6	29.6	14.8	15
	F1Cr411	4 pm – 6 pm	2	41	14.6	29.6	14.8	15
	F1Cr412	8 am – 2 pm	6	41	14.6	29.6	4.9	5
	F1Cr413	12 pm – 2 pm	2	41	14.6	29.6	14.8	15
	F1Cr414	8 am – 12 pm	4	41	14.6	29.6	7.4	7
Classroom (in class)	F2Cr111	12 pm – 2 pm	2	11	3.9	7.9	4	4
	F2Cr112	10 am – 12 pm	2	11	3.9	7.9	4	4
	F2Cr113	10 am – 2 pm	4	11	3.9	7.9	2	2
	F2Cr212	8 am – 11 am	3	21	7.5	15.2	5.1	5
	F2Cr213	8 am – 10 am	2	21	7.5	15.2	7.6	8
	Total	-	**29**	**280**	**100**	**202.1**	**79.3**	**80**
	F1Cr411	2 pm - 4 pm	4	20	25	12.2	3	3
	F1Cr412	2 pm - 4 pm	2	20	25	12.2	6.1	6
Classroom (free hours)	F1Cr413	2 pm - 4 pm	4	20	25	12.2	3	3
	F1Cr413	2 pm - 3 pm	2	20	25	12.2	6.1	6
	Total	-	**12**	**80**	**100**	**48.8**	**18.3**	**18**
	F1Lab	4 pm - 6 pm	2	21	50	13.9	7	7
Laboratory	F2Lab2	4 pm - 6 pm	2	21	50	13.9	7	7
	Total	-	**4**	**42**	**100**	**27.9**	**13.9**	**14**
	F0Comp	12 am - 2 pm	2	21	50	13.9	7	7
Computer room	F0Comp	4 pm - 6 pm	2	21	50	13.9	7	7
	Total	-	**4**	**42**	**100**	**27.9**	**13.9**	**14**
	F0Work	6 pm – 8 pm	2	40	50	13.9	7	7
Work room	F2Work	6 pm – 8 pm	2	40	50	13.9	7	7
	Total		**4**	**80**	**100**	**27.9**	**13.9**	**14**

Table A.11: Distribution of cell phones connection time according with second criterion on Wednesday.

Wednesday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Percentage of the total occupancy [%]**	**Cell phones connection time [h]**	**Cell phones connected in the class (no rounding)**	**Cell phones connected in class (rounding)**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	41	26.5	29.5	4.9	5
	F1Cr413	12 pm – 2 pm	2	41	26.5	29.5	14.7	15
	F1Cr414	8 am – 12 pm	4	41	26.5	29.5	7.4	7
	F2Cr112	12 pm – 2 pm	2	11	7.1	7.9	4	4
	F2Cr211	12 pm – 2 pm	2	21	13.5	15.1	7.6	8
	Total	-	**16**	**155**	**100**	**111.5**	**38.6**	**39**
Classroom (free hours)	F1Cr411	2 pm - 6 pm	4	20	25	34.9	8.7	9
	F1Cr412	8 am - 6 pm	10	20	25	34.9	3.5	3
	F1Cr413	2 pm - 4 pm	2	20	25	34.9	17.4	17
	F1Cr414	2 pm - 6 pm	4	20	25	34.9	8.7	9
	Total	-	**20**	**80**	**100**	**139.4**	**38.3**	**38**
Laboratory	F1Lab	8 am – 2 pm	6	21	100	41.8	7	7
	Total	-	**6**	**21**	**100**	**41.8**	**7**	**7**
Computer room	F0Comp	4 pm - 6 pm	2	21	100	13.9	7	7
	Total	-	**2**	**21**	**100**	**13.9**	**7**	**7**
Work room	F0Work	6 pm – 8 pm	2	40	50	13.9	7	7
	F2Work	6 pm – 8 pm	2	40	50	13.9	7	7
	Total	-	**4**	**80**	**100**	**27.9**	**13.9**	**14**

Table A.12: Distribution of cell phones connection time according with second criterion on Thursday.

			Thursday					
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Percentage of the total occupancy [%]**	**Cell phones connection time [h]**	**Cell phones connected in the class (no rounding)**	**Cell phones connected in class (rounding)**
	F1Cr411	8 am – 2 pm	6	41	13.2	26.7	4.5	4
	F1Cr411	4 pm – 6 pm	2	41	13.2	26.7	13.4	13
	F1Cr412	8 am – 12 pm	4	41	13.2	26.7	6.7	7
	F1Cr413	12 pm – 2 pm	2	41	13.2	26.7	13.4	13
	F1Cr414	12 pm – 2 pm	2	41	13.2	26.7	13.4	13
Classroom (in class)	F1Cr414	4 pm – 6 pm	2	41	13.2	26.7	13.4	13
	F2Cr112	10 am – 12 pm	2	11	3.5	7.2	3.6	4
	F2Cr113	10 am – 2 pm	4	11	3.5	7.2	1.8	2
	F2Cr212	8 am – 11 am	3	21	6.8	13.7	4.6	5
	F2Cr213	8 am – 10 am	2	21	6.8	13.7	6.8	7
	Total	-	**29**	**310**	**100**	**202.1**	**81.4**	**81**
	F1Cr411	2 pm - 4 pm	2	20	25	12.2	6.1	6
	F1Cr412	2 pm - 3 pm	1	20	25	12.2	12.2	12
Classroom (free hours)	F1Cr413	2 pm - 4 pm	2	20	25	12.2	6.1	6
	F1Cr414	2 pm - 4 pm	2	20	25	12.2	6.1	6
	Total	-	**7**	**80**	**100**	**48.8**	**30.5**	**30**
	F1Lab	12 pm - 2 pm	2	21	33.3	13.9	7	7
Laboratory	F1Lab	4 pm - 6 pm	2	21	33.3	13.9	7	7
	F2Lab2	4 pm - 6 pm	2	21	33.3	13.9	7	7
	Total	-	**6**	**63**	**100**	**41.8**	**20.9**	**21**
Computer room	F0Comp	12 pm - 2 pm	2	21	100	13.9	7	7
	Total	-	**2**	**21**	**100**	**13.9**	**7**	**7**
	F0Work	6 pm – 8 pm	2	40	50	13.9	7	7
Work room	F2Work	6 pm – 8 pm	2	40	50	13.9	7	7
	Total	-	**4**	**80**	**100**	**27.9**	**13.9**	**14**

Table A.13: Distribution of cell phones connection time according with second criterion on Friday.

Friday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Percentage of the total occupancy [%]**	**Cell phones connection time [h]**	**Cell phones connected in the class (no rounding)**	**Cell phones connected in class (rounding)**
Classroom (in class)	F1Cr412	8 am – 2 pm	6	41	66.1	36.9	6.1	6
	F2Cr211	8 am – 10 am	2	21	33.9	18.9	9.4	9
	Total	-	**8**	**62**	**100**	**55.8**	**15.6**	**15**
Classroom (free hours)	F1Cr411	8 am - 6 pm	10	20	25	55.8	5.6	6
	F1Cr412	2 pm - 4 pm	2	20	25	55.8	27.9	28
	F1Cr413	8 am - 6 pm	10	20	25	55.8	5.6	6
	F1Cr414	8 am - 6 pm	10	20	25	55.8	5.6	6
	Total	-	**32**	**80**	**100**	**223**	**44.6**	**46**
Laboratory	F2Lab1	8 am - 12 pm	4	21	100	27.9	7	7
	Total	-	**4**	**21**	**100**	**27.9**	**7**	**7**
Work room	F0Work	6 pm – 8 pm	2	40	50	13.9	7	7
	F2Work	6 pm – 8 pm	2	40	50	13.9	7	7
	Total	-	**4**	**80**	**100**	**27.9**	**13.9**	**14**

3. **Hours of use of the space:** In each space type, there are some spaces with the same occupancy and with different hours of space use. For example, on a Monday there are classes in the four bachelor base classrooms, but in two of them the class lasts six hours, in another it lasts four hours and in the last one only two hours. This situation only occurs in the Classrooms (in class) and in the Classrooms (free hours), so the third criterion only applies to these two space types. The third criterion is that the spaces with the same occupancy and with different hours of space use, distribute their equipment connection times, so the classes that last longer have more connection time.

Table A.14: Distribution of computers connection time according with third criterion on Monday.

Monday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Computers connection time (criterion 2) [h]**	**Computers connection time (criterion 3) [h]**	**Computers connected in the class (no rounding)**	**Computers connected in the class (rounding)**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	41	44.7	59.6	9.9	10
	F1Cr412	8 am – 2 pm	6	41	44.7	59.6	9.9	10
	F1Cr413	12 pm – 2 pm	2	41	44.7	19.9	9.9	10
	F1Cr414	8 am – 12 pm	4	41	44.7	39.7	9.9	10
	Total	-	**18**	**164**	**178.9**	**178.9**	**39.7**	**40**
Classroom (free hours)	F1Cr411	2 pm - 6 pm	4	20	25.4	36.4	9.1	9
	F1Cr412	2 pm - 4 pm	2	20	25.4	18.2	9.1	9
	F1Cr413	8 am - 12 pm	4	20	25.4	36.4	9.1	9
	F1Cr413	2 pm - 4 pm	2	20	25.4	18.2	9.1	9
	F1Cr414	2 pm - 4 pm	2	20	25.4	18.2	9.1	9
	Total	-	**14**	**100**	**127.2**	**127.2**	**45.4**	**45**

To obtain the computer connection time of the third criterion (column 7), it is necessary to distribute the total computer connection time of the second criterion (column 6) that a space type has between the spaces that make it up, so that the spaces with greater hours of use are those with the most computer connection time. To obtain the amount of computer connected (column 8) that will constantly be connected during a class, we divide the computers connection time of the third criterion (column 7) over the connection time (column 4). In the last column (column 9), we round the results from the previous column, as it is not possible to have fractional equipment units. This process applies in the same way from A.14 to A.23.

Table A.15: Distribution of computers connection time according with third criterion on Tuesday.

Tuesday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Computers connection time (criterion 2) [h]**	**Computers connection time (criterion 3) [h]**	**Computers connected in the class (no rounding)**	**Computers connected in the class (rounding)**
	F1Cr411	8 am – 10 pm	2	41	34.5	21.6	10.8	11
	F1Cr411	4 pm – 6 pm	2	41	34.5	21.6	10.8	11
	F1Cr412	8 am – 2 pm	6	41	34.5	64.7	10.8	11
	F1Cr413	12 pm – 2 pm	2	41	34.5	21.6	10.8	11
	F1Cr414	8 am – 12 pm	4	41	34.5	43.2	10.8	11
	Total	-	**16**	**205**	**172.7**	**172.7**	**54**	**55**
Classroom (in class)	F2Cr111	12 pm – 2 pm	2	11	9.3	6.9	3.5	3
	F2Cr112	10 am – 12 pm	2	11	9.3	6.9	3.5	3
	F2Cr113	10 am – 2 pm	4	11	9.3	13.9	3.5	3
	Total	-	**8**	**33**	**27.8**	**27.8**	**10.4**	**9**
	F2Cr212	8 am – 11 am	3	21	17.7	21.2	7.1	7
	F2Cr213	8 am – 10 am	2	21	17.7	14.1	7.1	7
	Total	-	**5**	**42**	**35.4**	**35.4**	**14.1**	**14**
	F1Cr411	2 pm - 4 pm	4	20	14.2	19	4.7	5
	F1Cr412	2 pm - 4 pm	2	20	14.2	9.5	4.7	5
Classroom (free hours)	F1Cr413	2 pm - 4 pm	4	20	14.2	19	4.7	5
	F1Cr413	2 pm - 3 pm	2	20	14.2	9.5	4.7	5
	Total	-	**12**	**80**	**56.9**	**56.9**	**19**	**20**

Table A.16: Distribution of computers connection time according with third criterion on Wednesday.

Wednesday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Computers connection time (criterion 2) [h]**	**Computers connection time (criterion 3) [h]**	**Computers connected in the class (no rounding)**	**Computers connected in the class (rounding)**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	41	47.4	71.1	11.9	12
	F1Cr413	12 pm – 2 pm	2	41	47.4	23.7	11.9	12
	F1Cr414	8 am – 12 pm	4	41	47.4	47.4	11.9	12
	Total	-	**12**	**123**	**142.3**	**142.3**	**35.6**	**36**
	F2Cr112	12 pm – 2 pm	2	11	12.7	12.7	6.4	6
	Total	-	**2**	**11**	**12.7**	**12.7**	**6.4**	**6**
	F2Cr211	12 pm – 2 pm	2	21	**24.3**	**24.3**	**12.1**	**12**
	Total	-	**2**	**21**	**24.3**	**24.3**	**12.1**	**12**
Classroom (free hours)	F1Cr411	2 pm - 6 pm	4	20	56	44.8	11.2	11
	F1Cr412	8 am - 6 pm	10	20	56	112.1	11.2	11
	F1Cr413	2 pm - 4 pm	2	20	56	22.4	11.2	11
	F1Cr414	2 pm - 6 pm	4	20	56	44.8	11.2	11
	Total	-	**20**	**80**	**224.1**	**224.1**	**44.8**	**44**

Table A.17: Distribution of computers connection time according with third criterion on Thursday.

				Thursday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Computers connection time (criterion 2) [h]**	**Computers connection time (criterion 3) [h]**	**Computers connected in the class (no rounding)**	**Computers connected in the class (rounding)**
	F1Cr411	8 am – 2 pm	6	41	36.7	73.4	12.2	12
	F1Cr411	4 pm – 6 pm	2	41	36.7	24.5	12.2	12
	F1Cr412	8 am – 12 pm	4	41	36.7	48.9	12.2	12
	F1Cr413	12 pm – 2 pm	2	41	36.7	24.5	12.2	12
	F1Cr414	12 pm – 2 pm	2	41	36.7	24.5	12.2	12
	F1Cr414	4 pm – 6 pm	2	41	36.7	24.5	12.2	12
Classroom (in class)	**Total**	-	**18**	**246**	**220.2**	**220.2**	**73.4**	**72**
	F2Cr112	10 am – 12 pm	2	11	9.8	6.6	3.3	3
	F2Cr113	10 am – 2 pm	4	11	9.8	13.1	3.3	3
	Total	-	**6**	**22**	**19.7**	**19.7**	**6.6**	**6**
	F2Cr212	8 am – 11 am	3	21	18.8	22.6	7.5	8
	F2Cr213	8 am – 10 am	2	21	18.8	15	7.5	8
	Total	-	**5**	**42**	**37.6**	**37.6**	**15**	**16**
	F1Cr411	2 pm - 4 pm	2	20	16.7	19.1	9.6	10
	F1Cr412	2 pm - 3 pm	1	20	16.7	9.6	9.6	10
Classroom (free hours)	F1Cr413	2 pm - 4 pm	2	20	16.7	19.1	9.6	10
	F1Cr414	2 pm - 4 pm	2	20	16.7	19.1	9.6	10
	Total	-	**7**	**80**	**67**	**67**	**38.3**	**40**

Table A.18: Distribution of computers connection time according with third criterion on Friday.

Friday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Computers connection time (criterion 2) [h]**	**Computers connection time (criterion 3) [h]**	**Computers connected in the class (no rounding)**	**Computers connected in the class (rounding)**
Classroom (free hours)	F1Cr411	8 am - 6 pm	10	20	55.8	69.7	7	7
	F1Cr412	2 pm - 4 pm	2	20	55.8	13.9	7	7
	F1Cr413	8 am - 6 pm	10	20	55.8	69.7	7	7
	F1Cr414	8 am - 6 pm	10	20	55.8	69.7	7	7
	Total	-	**32**	**104**	**223**	**223**	**27.9**	**28**

Table A.19: Distribution of cell phones connection time according with third criterion on Monday.

Monday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Hours with connected cell phones (criterion 2) [h]**	**Cell phones connection time (criterion 3) [h]**	**Cell phones connected in the class (no rounding)**	**Cell phones connected in the class (rounding)**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	41	34.3	45.7	7.6	8
	F1Cr412	8 am – 2 pm	6	41	34.3	45.7	7.6	8
	F1Cr413	12 pm – 2 pm	2	41	34.3	15.2	7.6	8
	F1Cr414	8 am – 12 pm	4	41	34.3	30.5	7.6	8
	Total	-	**18**	**164**	**137.2**	**137.2**	**30.5**	**32**
Classroom (free hours)	F1Cr411	2 pm - 6 pm	4	20	19.5	27.9	7	7
	F1Cr412	2 pm - 4 pm	2	20	19.5	13.9	7	7
	F1Cr413	8 am - 12 pm	4	20	19.5	27.9	7	7
	F1Cr413	2 pm - 4 pm	2	20	19.5	13.9	7	7
	F1Cr414	2 pm - 4 pm	2	20	19.5	13.9	7	7
	Total	-	**14**	**100**	**97.6**	**97.6**	**34.9**	**35**

Table A.20: Distribution of cell phones connection time according with third criterion on Tuesday.

Tuesday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Hours with connected cell phones (criterion 2) [h]**	**Cell phones connection time (criterion 3) [h]**	**Cell phones connected in the class (no rounding)**	**Cell phones connected in the class (rounding)**
Classroom (in class)	F1Cr411	8 am – 10 pm	2	41	29.6	18.5	9.2	9
	F1Cr411	4 pm – 6 pm	2	41	29.6	18.5	9.2	9
	F1Cr412	8 am – 2 pm	6	41	29.6	55.5	9.2	9
	F1Cr413	12 pm – 2 pm	2	41	29.6	18.5	9.2	9
	F1Cr414	8 am – 12 pm	4	41	29.6	37	9.2	9
	Total	-	**16**	**205**	**148**	**148**	**46.2**	**45**
	F2Cr111	12 pm – 2 pm	2	11	7.9	6	3	3
	F2Cr112	10 am – 12 pm	2	11	7.9	6	3	3
	F2Cr113	10 am – 2 pm	4	11	7.9	11.9	3	3
	Total		**8**	**33**	**23.8**	**23.8**	**8.9**	**9**
	F2Cr212	8 am – 11 am	3	21	15.2	18.2	6.1	6
	F2Cr213	8 am – 10 am	2	21	15.2	12.1	6.1	6
	Total	-	**5**	**42**	**30.3**	**30.3**	**12.1**	**12**
Classroom (free hours)	F1Cr411	2 pm - 4 pm	4	20	12.2	16.3	4.1	4
	F1Cr412	2 pm - 4 pm	2	20	12.2	8.1	4.1	4
	F1Cr413	2 pm - 4 pm	4	20	12.2	16.3	4.1	4
	F1Cr413	2 pm - 3 pm	2	20	12.2	8.1	4.1	4
	Total	-	**12**	**80**	**48.8**	**48.8**	**16.3**	**16**

Table A.21: Distribution of cell phones connection time according with third criterion on Wednesday.

Wednesday								
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Hours with connected cell phones (criterion 2) [h]**	**Cell phones connection time (criterion 3) [h]**	**Cell phones connected in the class (no rounding)**	**Cell phones connected in the class (rounding)**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	41	29.5	44.2	7.4	7
	F1Cr413	12 pm – 2 pm	2	41	29.5	14.7	7.4	7
	F1Cr414	8 am – 12 pm	4	41	29.5	29.5	7.4	7
	Total	-	**12**	**123**	**88.5**	**88.5**	**22.1**	**21**
	F2Cr112	12 pm – 2 pm	2	11	7.9	7.9	4	4
	Total	-	**2**	**11**	**7.9**	**7.9**	**4**	**4**
	F2Cr211	12 pm – 2 pm	2	21	**15.1**	**15.1**	**7.6**	**8**
	Total	-	**2**	**21**	**15.1**	**15.1**	**7.6**	**8**
Classroom (free hours)	F1Cr411	2 pm - 6 pm	4	20	34.9	27.9	7	7
	F1Cr412	8 am - 6 pm	10	20	34.9	69.7	7	7
	F1Cr413	2 pm - 4 pm	2	20	34.9	13.9	7	7
	F1Cr414	2 pm - 6 pm	4	20	34.9	27.9	7	7
	Total		**20**	**80**	**139.4**	**139.4**	**27.9**	**28**

Table A.22: Distribution of cell phones connection time according with third criterion on Thursday.

				Thursday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Hours with connected cell phones (criterion 2) [h]**	**Cell phones connection time (criterion 3) [h]**	**Cell phones connected in the class (no rounding)**	**Cell phones connected in the class (rounding)**
	F1Cr411	8 am – 2 pm	6	41	26.7	53.5	8.9	9
	F1Cr411	4 pm – 6 pm	2	41	26.7	17.8	8.9	9
	F1Cr412	8 am – 12 pm	4	41	26.7	35.6	8.9	9
	F1Cr413	12 pm – 2 pm	2	41	26.7	17.8	8.9	9
	F1Cr414	12 pm – 2 pm	2	41	26.7	17.8	8.9	9
	F1Cr414	4 pm – 6 pm	2	41	26.7	17.8	8.9	9
Classroom (in class)	**Total**	-	**18**	**246**	**160.4**	**160.4**	**53.5**	**54**
	F2Cr112	10 am – 12 pm	2	11	7.2	4.8	2.4	2
	F2Cr113	10 am – 2 pm	4	11	7.2	9.6	2.4	2
	Total	-	**6**	**22**	**14.3**	**14.3**	**4.8**	**4**
	F2Cr212	8 am – 11 am	3	21	13.7	16.4	5.5	5
	F2Cr213	8 am – 10 am	2	21	13.7	11	5.5	5
	Total	-	**5**	**42**	**27.4**	**27.4**	**11**	**10**
	F1Cr411	2 pm - 4 pm	2	20	12.2	13.9	7	7
	F1Cr412	2 pm - 3 pm	1	20	12.2	7	7	7
Classroom (free hours)	F1Cr413	2 pm - 4 pm	2	20	12.2	13.9	7	7
	F1Cr414	2 pm - 4 pm	2	20	12.2	13.9	7	7
	Total	-	**7**	**80**	**48.8**	**48.8**	**27.9**	**28**

Table A.23: Distribution of cell phones connection time according with third criterion on Friday.

				Friday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Occupancy [-]**	**Hours with connected cell phones (criterion 2) [h]**	**Cell phones connection time (criterion 3) [h]**	**Cell phones connected in the class (no rounding)**	**Cell phones connected in the class (rounding)**
Classroom (free hours)	F1Cr411	8 am - 6 pm	10	20	55.8	69.7	7	7
	F1Cr412	2 pm - 4 pm	2	20	55.8	13.9	7	7
	F1Cr413	8 am - 6 pm	10	20	55.8	69.7	7	7
	F1Cr414	8 am - 6 pm	10	20	55.8	69.7	7	7
	Total	-	**32**	**104**	**223**	**223**	**27.9**	**28**

The calculations that are made in this entire section are to estimate the amount, hours of connection, and schedules of computers and cell phones that are used in the new IER building. The results obtained in this subsection were added to the EnergyPlus numerical model to calculate the total energy consumption of the building. The information required for these two equipments was estimated using three distribution criteria. It is essential to consider that not all spaces require the use of the three criteria, so in order to collect the correct information from the equipments analysed in this subsection, it is necessary to carefully read the conditions of each criterion, since there are some equipments whose information in certain spaces is determined in the second criterion and there are other cases whose information is determined up to the third criterion.

A.2.2 Second group equipments

Th equipment that are in second group are projectors, televisions, exhaust fans and laboratory equipment. From the question 7 to 11 of the bachelor student survey, an average of the time that a projector is connected in a classroom on each weekday is obtained. From question 13, an average of the time that a TV is connected in a classroom on all weekdays is obtained. From the question 1 of the laboratory survey, an average of the time that a exhaust fan is connected in a laboratory on all weekdays is obtained. Finally, from the question 2 of the laboratory survey, the laboratory equipment that is most used in the classes and an average of the time that it is used per week were obtained. The results are listed below:

Projector

- Monday = 3.52 h
- Tuesday = 2.42 h
- Wednesday = 4.14 h
- Thursday = 2.9 h
- Friday = 3.28 h

Televisions

- All Weekdays = 0.28 h

Exhaust fans

- All Weekdays = 0.25 h

Laboratory equipment

- Power supply - 3 h
- Warming rack - 3 h
- Data logger- 3 h
- Fountain pumps - 2 h
- Drills - 2 h

For simplicity, all of the equipments in the laboratory are joined to create a single load called Laboratory equipment. With the data collected from the survey, it is assumed that this load is used an average of 3 hours per week and the power is assumed as the sum of all the average powers of the equipment that make up the load, that is, an estimate of 2000 W.

The most important characteristic of this equipment group is that their amount in a space is much less than the amount of the equipment in the first group. Most of the equipment is already installed within the space and few units are used by all occupants. In the classrooms, it is only considered a projector and a television per space. In the laboratories, there are consider 3 exhaust fans per space, while only one unit of laboratory equipment is considered per space.

The equipment connection time obtained from the survey only represent the opinion of one bachelor group, since each person answered based on their own experience. As there are four bachelor groups, to calculate the equipment connection time of the entire new building, it is necessary to multiply by four the equipment connection times listed above. The results are shown below:

Projector

- Monday = 14.08 h

- Tuesday = 9.68 h
- Wednesday = 16.56 h
- Thursday = 11.6 h
- Friday = 13. 12

Televisions

- All Weekdays = 1.12 h

Exhaust fans

- All Weekdays = 1 h

Laboratory equipment

- All Weekdays = 12 h

To calculate the equipment connection times in this group, only the third criterion of the previous section is used. The first criterion cannot be applied because each equipment is used only in one space type, so percentages of time spent by occupants in each space type cannot be obtained. The second criterion cannot be used because it depends on the occupancy and, with this equipment group, if the occupancy in a space increase or decrease, the same amount of equipments continues to be used, the same connection time and in the same connection schedule. Therefore, only the third criterion can be applied, which consists of distributing the equipment connection time in the spaces, considering that the spaces with longer classes will be the ones with more equipment connection time.

On the contrary to the Tables of the first group of equipment, this time the amount of equipments connected in the class is not calculated, since these numbers have already been previously defined. From Table A.24 to A.43 the results for the second group of equipment are shown.

Table A.24: Distribution of projectors connection time according with third criterion on Monday.

Monday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Projectors connection time (criterion 3) [h]**
	F1Cr411	8 am – 2 pm	6	3
	F1Cr412	8 am – 2 pm	6	3
	F1Cr413	12 pm – 2 pm	2	1
	F1Cr414	8 am – 12 pm	4	2
	F2Cr111	12 pm – 2 pm	2	1
Classroom (in class)	F2Cr111	4 pm – 6 pm	2	1
	F2Cr112	12 pm – 2 pm	2	1
	F2Cr112	4 pm – 6 pm	2	1
	F2Cr211	12 pm – 2 pm	2	1
	F2Cr211	4 pm – 6 pm	2	1
	Total	-	**30**	**14.1**

Table A.25: Distribution of projectors connection time according with third criterion on Tuesday.

Tuesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Projectors connection time (criterion 3) [h]**
Classroom (in class)	F1Cr411	8 am – 10 pm	2	1
	F1Cr411	4 pm – 6 pm	2	1
	F1Cr412	8 am – 2 pm	6	2
	F1Cr413	12 pm – 2 pm	2	1
	F1Cr414	8 am – 12 pm	4	1
	F2Cr111	12 pm – 2 pm	2	1
	F2Cr112	10 am – 12 pm	2	1
	F2Cr113	10 am – 2 pm	4	1
	F2Cr212	8 am – 11 am	3	1
	F2Cr213	8 am – 10 am	2	1
	Total	-	**29**	**9.7**

Table A.26: Distribution of projectors connection time according with third criterion on Wednesday.

Wednesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Projectors connection time (criterion 3) [h]**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	6
	F1Cr413	12 pm – 2 pm	2	2
	F1Cr414	8 am – 12 pm	4	4
	F2Cr112	12 pm – 2 pm	2	2
	F2Cr211	12 pm – 2 pm	2	2
	Total	-	**16**	**16.6**

Table A.27: Distribution of projectors connection time according with third criterion on Thursday.

Thursday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Projectors connection time (criterion 3) [h]**
	F1Cr411	8 am – 2 pm	6	2
	F1Cr411	4 pm – 6 pm	2	1
	F1Cr412	8 am – 12 pm	4	2
	F1Cr413	12 pm – 2 pm	2	1
	F1Cr414	12 pm – 2 pm	2	1
Classroom (in class)	F1Cr414	4 pm – 6 pm	2	1
	F2Cr112	10 am – 12 pm	2	1
	F2Cr113	10 am – 2 pm	4	2
	F2Cr212	8 am – 11 am	3	1
	F2Cr213	8 am – 10 am	2	1
	Total	-	**29**	**11.6**

Table A.28: Distribution of projectors connection time according with third criterion on Friday.

Friday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Hours with connected projectors (criterion 3) [h]**
	F1Cr412	8 am – 2 pm	6	10
Classroom (in class)	F2Cr211	8 am – 10 am	2	1
	Total	-	**8**	**10.7**

Table A.29: Distribution of televisions connection time according with third criterion on Monday.

Monday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**TV connection time(criterion 3) [h]**
	F1Cr411	8 am – 2 pm	6	0.6
Classroom (in class)	F1Cr412	8 am – 2 pm	6	0.6
	Total	-	**12**	**1.1**

Table A.30: Distribution of televisions connection time according with third criterion on Tuesday.

Tuesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**TV connection time(criterion 3) [h]**
Classroom (in class)	F1Cr411	8 am – 10 pm	2	0.6
	F1Cr411	4 pm – 6 pm	2	0.6
	Total	-	**4**	**1.1**

Table A.31: Distribution of televisions connection time according with third criterion on Wednesday.

Wednesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**TV connection time (criterion 3) [h]**
Classroom (in class)	F2Cr112	12 pm – 2 pm	2	0.6
	F2Cr211	12 pm – 2 pm	2	0.6
	Total	-	**4**	**1.1**

Table A.32: Distribution of televisions connection time according with third criterion on Thursday.

Thursday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Hours with connected TV (criterion 3) [h]**
Classroom (in class)	F1Cr414	12 pm – 2 pm	2	0.6
	F1Cr414	4 pm – 6 pm	2	0.6
	Total	-	**4**	**1.1**

Table A.33: Distribution of televisions connection time according with third criterion on Friday.

Friday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**TV connection time (criterion 3) [h]**
Classroom (in class)	F1Cr412	8 am – 2 pm	6	1
	F2Cr211	8 am – 10 am	2	0
	Total	-	**8**	**1**

Table A.34: Distribution of exhaust fans connection time according with third criterion on Monday.

Monday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Exhaust fans connection time(criterion 3) [h]**
Laboratory	F1Lab	-	0	0
	F2Lab1	-	0	0
	F2Lab2	-	0	0
	Total	-	**0**	**0**

Table A.35: Distribution of exhaust fans connection time according with third criterion on Tuesday.

Tuesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Exhaust fans connection time (criterion 3) [h]**
Laboratory	F1Lab	4 pm - 6 pm	2	0.5
	F2Lab2	4 pm - 6 pm	2	0.5
	Total	-	**4**	**1**

Table A.36: Distribution of exhaust fans connection time according with third criterion on Wednesday.

Wednesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Exhaust fans connection time (criterion 3) [h]**
Laboratory	F1Lab	8 am – 2 pm	6	1
	Total	-	**6**	**1**

Table A.37: Distribution of exhaust fans connection time according with third criterion on Thursday.

Thursday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Exhaust fans connection time (criterion 3) [h]**
Laboratory	F1Lab	12 pm - 2 pm	2	0.5
	F1Lab	4 pm - 6 pm	2	0.5
	Total	-	**4**	**1**

Table A.38: Distribution of exhaust fans connection time according with third criterion on Friday.

Friday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Exhaust fans connection time (criterion 3) [h]**
Laboratory	F2Lab1	8 am - 12 pm	4	1
	Total	-	**4**	**1**

Table A.39: Distribution of laboratory equipment connection time according with third criterion on Monday.

Monday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Laboratory equipment connection time (criterion 3) [h]**
Laboratory	F1Lab	NA	0	0
	F2Lab1	NA	0	0
	F2Lab2	NA	0	0
	Total	-	**0**	**0**

Table A.40: Distribution of laboratory equipment connection time according with third criterion on Tuesday.

Tuesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Laboratory equipment connection time (criterion 3) [h]**
Laboratory	F1Lab	4 pm - 6 pm	2	1.5
	F2Lab2	4 pm - 6 pm	2	1.5
	Total	-	**4**	**3**

Table A.41: Distribution of laboratory equipment connection time according with third criterion on Wednesday.

Wednesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Laboratory equipment connection time (criterion 3) [h]**
Laboratory	F1Lab	8 am – 2 pm	6	3
	Total	-	**6**	**3**

Table A.42: Distribution of laboratory equipment connection time according with third criterion on Thursday.

Thursday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Laboratory equipment connection time (criterion 3) [h]**
Laboratory	F1Lab	12 pm - 2 pm	2	1.5
	F1Lab	4 pm - 6 pm	2	1.5
	Total	-	**4**	**3**

Table A.43: Distribution of laboratory equipment connection time according with third criterion on Friday.

Friday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Laboratory equipment connection time (criterion 3) [h]**
Laboratory	F2Lab1	8 am - 12 pm	4	3
	Total	-	**4**	**3**

A.3 Summary of results

This section presents the most relevant information to add some electrical equipment loads in the numerical model of the study case. If you want to know in greater detail how each value was obtained, it is necessary to review the methodology of the previous section.

Table A.44: Connection schedule, connection time and amount of computers connected in each space on Monday.

Monday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Amount per space [-]**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	10
	F1Cr412	8 am – 2 pm	6	10
	F1Cr413	12 pm – 2 pm	2	10
	F1Cr414	8 am – 12 pm	4	10
	F2Cr111	12 pm – 2 pm	2	6
	F2Cr111	4 pm – 6 pm	2	6
	F2Cr112	12 pm – 2 pm	2	6
	F2Cr112	4 pm – 6 pm	2	6
	F2Cr211	12 pm – 2 pm	2	11
	F2Cr211	4 pm – 6 pm	2	11
Classroom (free hours)	F1Cr411	2 pm - 6 pm	4	9
	F1Cr412	2 pm - 4 pm	2	9
	F1Cr413	8 am - 12 pm	4	9
	F1Cr413	2 pm - 4 pm	2	9
	F1Cr414	2 pm - 4 pm	2	9
Work room	F0Work	6 pm – 8 pm	2	9
	F2Work	6 pm – 8 pm	2	9

Table A.45: Connection schedule, connection time and amount of computers connected in each space on Tuesday

Tuesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Amount per space [-]**
Classroom (in class)	F1Cr411	8 am – 10 pm	2	11
	F1Cr411	4 pm – 6 pm	2	11
	F1Cr412	8 am – 2 pm	6	11
	F1Cr413	12 pm – 2 pm	2	11
	F1Cr414	8 am – 12 pm	4	11
	F2Cr111	12 pm – 2 pm	2	3
	F2Cr112	10 am – 12 pm	2	3
	F2Cr113	10 am – 2 pm	4	3
	F2Cr212	8 am – 11 am	3	7
	F2Cr213	8 am – 10 am	2	7
Classroom (free hours)	F1Cr411	2 pm - 4 pm	4	5
	F1Cr412	2 pm - 4 pm	2	5
	F1Cr413	2 pm - 4 pm	4	5
	F1Cr413	2 pm - 3 pm	2	5
Laboratory	F1Lab	4 pm - 6 pm	2	8
	F2Lab2	4 pm - 6 pm	2	8
Work room	F0Work	6 pm – 8 pm	2	8
	F2Work	6 pm – 8 pm	2	8

Table A.46: Connection schedule, connection time and amount of computers connected in each space on Monday.

Wednesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Amount per space [-]**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	12
	F1Cr413	12 pm – 2 pm	2	12
	F1Cr414	8 am – 12 pm	4	12
	F2Cr112	12 pm – 2 pm	2	6
	F2Cr211	12 pm – 2 pm	2	12
Classroom (free hours)	F1Cr411	2 pm - 6 pm	4	11
	F1Cr412	8 am - 6 pm	10	11
	F1Cr413	2 pm - 4 pm	2	11
	F1Cr414	2 pm - 6 pm	4	11
Laboratory	F1Lab	8 am – 2 pm	6	11
Work room	F0Work	6 pm – 8 pm	2	11
	F2Work	6 pm – 8 pm	2	11

Table A.47: Connection schedule, connection time and amount of computers connected in each space on Thursday.

Thursday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Amount per space [-]**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	12
	F1Cr411	4 pm – 6 pm	2	12
	F1Cr412	8 am – 12 pm	4	12
	F1Cr413	12 pm – 2 pm	2	12
	F1Cr414	12 pm – 2 pm	2	12
	F1Cr414	4 pm – 6 pm	2	12
	F2Cr112	10 am – 12 pm	2	3
	F2Cr113	10 am – 2 pm	4	3
	F2Cr212	8 am – 11 am	3	8
	F2Cr213	8 am – 10 am	2	8
Classroom (free hours)	F1Cr411	2 pm - 4 pm	2	10
	F1Cr412	2 pm - 3 pm	1	10
	F1Cr413	2 pm - 4 pm	2	10
	F1Cr414	2 pm - 4 pm	2	10
Laboratory	F1Lab	12 pm - 2 pm	2	10
	F1Lab	4 pm - 6 pm	2	10
	F2Lab2	4 pm - 6 pm	2	10
Work room	F0Work	6 pm – 8 pm	2	10
	F2Work	6 pm – 8 pm	2	10

Table A.48: Connection schedule, connection time and amount of computers connected in each space on Friday.

Friday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Amount per space [-]**
Classroom (in class)	F1Cr412	8 am – 2 pm	6	6
	F2Cr211	8 am – 10 am	2	9
Classroom (free hours)	F1Cr411	8 am - 6 pm	10	7
	F1Cr412	2 pm - 4 pm	2	7
	F1Cr413	8 am - 6 pm	10	7
	F1Cr414	8 am - 6 pm	10	7
Laboratory	F2Lab1	8 am - 12 pm	4	7
Work room	F0Work	6 pm – 8 pm	2	7
	F2Work	6 pm – 8 pm	2	7

Table A.49: Connection schedule, connection time and amount of cell phones connected in each space on Monday.

Monday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Amount per space [-]**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	8
	F1Cr412	8 am – 2 pm	6	8
	F1Cr413	12 pm – 2 pm	2	8
	F1Cr414	8 am – 12 pm	4	8
	F2Cr111	12 pm – 2 pm	2	5
	F2Cr111	4 pm – 6 pm	2	5
	F2Cr112	12 pm – 2 pm	2	5
	F2Cr112	4 pm – 6 pm	2	5
	F2Cr211	12 pm – 2 pm	2	9
	F2Cr211	4 pm – 6 pm	2	9
Classroom (free hours)	F1Cr411	2 pm - 6 pm	4	7
	F1Cr412	2 pm - 4 pm	2	7
	F1Cr413	8 am - 12 pm	4	7
	F1Cr413	2 pm - 4 pm	2	7
	F1Cr414	2 pm - 4 pm	2	7
Work room	F0Work	6 pm – 8 pm	2	7
	F2Work	6 pm – 8 pm	2	7

Table A.50: Connection schedule, connection time and amount of cell phones connected in each space on Tuesday.

Tuesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Amount per space [-]**
Classroom (in class)	F1Cr411	8 am – 10 pm	2	9
	F1Cr411	4 pm – 6 pm	2	9
	F1Cr412	8 am – 2 pm	6	9
	F1Cr413	12 pm – 2 pm	2	9
	F1Cr414	8 am – 12 pm	4	9
	F2Cr111	12 pm – 2 pm	2	3
	F2Cr112	10 am – 12 pm	2	3
	F2Cr113	10 am – 2 pm	4	3
	F2Cr212	8 am – 11 am	3	6
	F2Cr213	8 am – 10 am	2	6
Classroom (free hours)	F1Cr411	2 pm - 4 pm	2	4
	F1Cr412	2 pm - 3 pm	1	7
	F1Cr413	2 pm - 4 pm	2	4
	F1Cr414	2 pm - 4 pm	2	4
Laboratory	F1Lab	4 pm - 6 pm	2	7
	F2Lab2	4 pm - 6 pm	2	7
Computer room	F0Comp	12 am - 2 pm	2	7
	F0Comp	4 pm - 6 pm	2	7
Work room	F0Work	6 pm – 8 pm	2	7
	F2Work	6 pm – 8 pm	2	7

Table A.51: Connection schedule, connection time and amount of cell phones connected in each space on Wednesday.

Wednesday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Amount per space [-]**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	7
	F1Cr413	12 pm – 2 pm	2	7
	F1Cr414	8 am – 12 pm	4	7
	F2Cr112	12 pm – 2 pm	2	4
	F2Cr211	12 pm – 2 pm	2	8
Classroom (free hours)	F1Cr411	2 pm - 6 pm	4	7
	F1Cr412	8 am - 6 pm	10	7
	F1Cr413	2 pm - 4 pm	2	7
	F1Cr414	2 pm - 6 pm	4	7
Laboratory	F1Lab	8 am – 2 pm	6	7
Computer room	F0Comp	4 pm - 6 pm	2	7
Work room	F0Work	6 pm – 8 pm	2	7
	F2Work	6 pm – 8 pm	2	7

Table A.52: Connection schedule, connection time and amount of cell phones connected in each space on Thursday.

Thursday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Amount per space [-]**
Classroom (in class)	F1Cr411	8 am – 2 pm	6	9
	F1Cr411	4 pm – 6 pm	2	9
	F1Cr412	8 am – 12 pm	4	9
	F1Cr413	12 pm – 2 pm	2	9
	F1Cr414	12 pm – 2 pm	2	9
	F1Cr414	4 pm – 6 pm	2	9
	F2Cr112	10 am – 12 pm	2	4
	F2Cr113	10 am – 2 pm	4	4
	F2Cr212	8 am – 11 am	3	10
	F2Cr213	8 am – 10 am	2	10
Classroom (free hours)	F1Cr411	2 pm - 4 pm	2	4
	F1Cr412	2 pm - 3 pm	1	7
	F1Cr413	2 pm - 4 pm	2	4
	F1Cr414	2 pm - 4 pm	2	4
Laboratory	F1Lab	12 pm - 2 pm	2	7
	F1Lab	4 pm - 6 pm	2	7
	F2Lab2	4 pm - 6 pm	2	7
Computer room	F0Comp	12 pm - 2 pm	2	7
Work room	F0Work	6 pm – 8 pm	2	7
	F2Work	6 pm – 8 pm	2	7

Table A.53: Connection schedule, connection time and amount of cell phones connected in each space on Friday.

Friday				
Space type	**Space**	**Connection schedule**	**Connection time [h]**	**Amount per space [-]**
Classroom (in class)	F1Cr412	8 am – 2 pm	6	6
	F2Cr211	8 am – 10 am	2	9
Classroom (free hours)	F1Cr411	8 am - 6 pm	10	7
	F1Cr412	2 pm - 4 pm	2	7
	F1Cr413	8 am - 6 pm	10	7
	F1Cr414	8 am - 6 pm	10	7
Laboratory	F2Lab1	8 am - 12 pm	4	7
Work room	F0Work	6 pm – 8 pm	2	7
	F2Work	6 pm – 8 pm	2	7

Table A.54: Connection schedule and connection time of projectors in each space on Monday.

Monday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Classroom (in class)	F1Cr411	8 am – 2 pm	3
	F1Cr412	8 am – 2 pm	3
	F1Cr413	12 pm – 2 pm	1
	F1Cr414	8 am – 12 pm	2
	F2Cr111	12 pm – 2 pm	1
	F2Cr111	4 pm – 6 pm	1
	F2Cr112	12 pm – 2 pm	1
	F2Cr112	4 pm – 6 pm	1
	F2Cr211	12 pm – 2 pm	1
	F2Cr211	4 pm – 6 pm	1

Table A.55: Connection schedule and connection time of projectors in each space on Tuesday.

Tuesday			
Space type	**Space**	**Connection schedule**	**Connection time**
Classroom (in class)	F1Cr411	8 am – 10 pm	1
	F1Cr411	4 pm – 6 pm	1
	F1Cr412	8 am – 2 pm	2
	F1Cr413	12 pm – 2 pm	1
	F1Cr414	8 am – 12 pm	1
	F2Cr111	12 pm – 2 pm	1
	F2Cr112	10 am – 12 pm	1
	F2Cr113	10 am – 2 pm	1
	F2Cr212	8 am – 11 am	1
	F2Cr213	8 am – 10 am	1

Table A.56: Connection schedule and connection time of projectors in each space on Wednesday.

Wednesday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Classroom (in class)	F1Cr411	8 am – 2 pm	6
	F1Cr413	12 pm – 2 pm	2
	F1Cr414	8 am – 12 pm	4
	F2Cr112	12 pm – 2 pm	2
	F2Cr211	12 pm – 2 pm	2

Table A.57: Connection schedule and connection time of projectors in each space on Thursday.

Thursday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Classroom (in class)	F1Cr411	8 am – 2 pm	2
	F1Cr411	4 pm – 6 pm	1
	F1Cr412	8 am – 12 pm	2
	F1Cr413	12 pm – 2 pm	1
	F1Cr414	12 pm – 2 pm	1
	F1Cr414	4 pm – 6 pm	1
	F2Cr112	10 am – 12 pm	1
	F2Cr113	10 am – 2 pm	2
	F2Cr212	8 am – 11 am	1
	F2Cr213	8 am – 10 am	1

Table A.58: Connection schedule and connection time of projectors in each space on Friday.

Friday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Classroom (in class)	F1Cr412	8 am – 2 pm	10
	F2Cr211	8 am – 10 am	1

Table A.59: Connection schedule and connection time of televisions in each space on Monday.

Monday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Classroom (in class)	F1Cr411	8 am – 2 pm	0.6
	F1Cr412	8 am – 2 pm	0.6

Table A.60: Connection schedule and connection time of televisions in each space on Tuesday.

Tuesday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Classroom (in class)	F1Cr411	8 am – 10 pm	0.6
	F1Cr411	4 pm – 6 pm	0.6

Table A.61: Connection schedule and connection time of televisions in each space on Wednesday.

Wednesday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Classroom (in class)	F2Cr112	12 pm – 2 pm	0.6
	F2Cr211	12 pm – 2 pm	0.6

Table A.62: Connection schedule and connection time of televisions in each space on Thursday.

Thursday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Classroom (in class)	F1Cr414	12 pm – 2 pm	0.6
	F1Cr414	4 pm – 6 pm	0.6

Table A.63: Connection schedule and connection time of televisions in each space on Friday.

Friday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Classroom (in class)	F1Cr412	8 am – 2 pm	1
	F2Cr211	8 am – 10 am	0

Table A.64: Connection schedule and connection time of exhaust fans in each space on Monday.

Monday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Laboratory	F1Lab	-	0
	F2Lab1	-	0
	F2Lab2	-	0

Table A.65: Connection schedule and connection time of exhaust fans in each space on Tuesday.

Tuesday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Laboratory	F1Lab	4 pm - 6 pm	0.5
	F2Lab2	4 pm - 6 pm	0.5

Table A.66: Connection schedule and connection time of exhaust fans in each space on Wednesday.

Wednesday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Laboratory	F1Lab	8 am – 2 pm	1

Table A.67: Connection schedule and connection time of exhaust fans in each space on Monday.

Thursday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Laboratory	F1Lab	12 pm - 2 pm	0.5
	F1Lab	4 pm - 6 pm	0.5

Table A.68: Connection schedule and connection time of exhaust fans in each space on Friday.

Friday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Laboratory	F2Lab1	8 am - 12 pm	1

Table A.69: Connection schedule and connection time of laboratory equipment in each space on Monday.

Monday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Laboratory	F1Lab	NA	0
	F2Lab1	NA	0
	F2Lab2	NA	0

Table A.70: Connection schedule and connection time of laboratory equipment in each space on Tuesday.

Tuesday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Laboratory	F1Lab	4 pm - 6 pm	1.5
	F2Lab2	4 pm - 6 pm	1.5

Table A.71: Connection schedule and connection time of laboratory equipment in each space on Monday.

Wednesday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Laboratory	F1Lab	8 am – 2 pm	3

Table A.72: Connection schedule and connection time of laboratory equipment in each space on Thursday.

Thursday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Laboratory	F1Lab	12 pm - 2 pm	1.5
	F1Lab	4 pm - 6 pm	1.5

Table A.73: Connection schedule and connection time of laboratory equipment in each space on Friday.

Friday			
Space type	**Space**	**Connection schedule**	**Connection time [h]**
Laboratory	F2Lab1	8 am - 12 pm	3

Bibliography

ASHRAE. Standard 90.1-1989, energy efficient design of new buildings except low-rise residential buildings. *American Society of Heating Refrigerating and Air-conditioning Engineers, Atlanta*, 1989.

A. S. ASHRAE. Standard 90.1-2022, energy standard for buildings except low rise residential buildings. *American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc*, 2022.

I. ASHRAE. *2009 ASHRAE handbook: Fundamentals*. American Society of Heating, Refrigeration and Air-Conditioning Engineers, 2009.

L. C. Betancourt. *Simulación con Radiance de estrategias de iluminación natural en un espacio del IER*. PhD thesis, National Autonomous University of Mexico (UNAM), 2020.

CFE. Tarifa GDMTH, 2022. URL https://app.cfe.mx/Aplicaciones/CCFE/Tarifas/TarifasCRENegocio/Tarifas/GranDemandaMTH.aspx.

Diario Oficial. Condiciones de iluminación en los centros de trabajo, 2008.

EnergyStar. Energy star portfolio manager technical reference: Source energy. *EPA Energy Star Portfolio Manager*, 2013.

EnergyStar. What is Energy Use Intensity (EUI)?, 8 2021. URL https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager/understand-metrics/what-energy.

W. Feng, Q. Zhang, H. Ji, R. Wang, N. Zhou, Q. Ye, B. Hao, Y. Li, D. Luo, and S. S. Y. Lau. A review of net zero energy buildings in hot and humid climates: Experience learned from 34 case study buildings. *Renewable and Sustainable Energy Reviews*, 114: 109303, 2019.

Gobierno de México and CONUEE. Herramienta para el ajuste del factor de potencia, 5 2016. URL https://www.gob.mx/conuee/acciones-y-programas/herramienta-para-el-ajuste-del-factor-de-potencia.

IEA. Buildings. Technical report, 9 2023. URL https://www.iea.org/reports/buildings.

I. G. Kerdan, D. M. Gálvez, R. Raslan, and P. Ruyssevelt. Modelling the energy and exergy utilisation of the mexican non-domestic sector: A study by climatic regions. *Energy Policy*, 77:191–206, 2015.

N. E. Klepeis, W. C. Nelson, W. R. Ott, J. P. Robinson, A. M. Tsang, P. Switzer, J. V. Behar, S. C. Hern, and W. H. Engelmann. The national human activity pattern survey (nhaps): a resource for assessing exposure to environmental pollutants. *Journal of Exposure Science & Environmental Epidemiology*, 11(3):231–252, 2001.

D. M. C. Lorentzen and M. A. McNeil. Electricity demand of non-residential buildings in mexico. *Sustainable Cities and Society*, 59:102165, 2020.

G. S. López Sánchez. Análisis del consumo de la energía eléctrica del instituto de energías renovables, 2018.

V. Mahajan, R. S. Srinivasan, A. R. Chini, and R. J. Ries. Space-level plug-load densities of educational buildings on university campuses. *Journal of Energy Engineering*, 143(2):04016041, 2017.

D. Morillón Galvéz and F. J. Ceballos Ochoa. *Metodología para la sustentabilidad energética de los edificios, Vivienda net zero energy.*, volume 1. Universidad Nacional Autónoma de México, 1 edition, 1 2015. URL https://aplicaciones.iingen.unam.mx/ConsultasSPII/DetallePublicacion.aspx?id=5002.

A. Nabil and J. Mardaljevic. Useful daylight illuminances: A replacement for daylight factors. *Energy and buildings*, 38(7):905–913, 2006.

K. Peterson, P. Torcellini, and R. Grant. A Common Definition for Zero Energy Buildings. Technical report, 9 2015. URL https://doi.org/10.2172/1884396.

Renesola. Renesola Virtus II Module 265-285W, 2023. URL https://es.enfsolar.com/pv/panel-datasheet/crystalline/30364.

I. Sartori, A. Napolitano, and K. Voss. Net zero energy buildings: A consistent definition framework. *Energy and buildings*, 48: 220–232, 2012.

Secretaría de Gobernación. NORMA Oficial Mexicana NOM-Q-27-1986 Calentadores para agua tipo almacenamiento a base de gas natural o gases licuados de petróleo. Technical report, 12 1986. URL https://dof.gob.mx/nota_detalle.php?codigo=4821401&fecha=04/12/1986#gsc.tab=0.

SEMARNAT. *Inventario nacional de emisiones de gases de efecto invernadero, 1990-2002*. Instituto Nacional de Ecología, 2021.

SENER. Balance Nacional de Energía 2022. Technical report, 2 2023. URL https://www.gob.mx/cms/uploads/attachment/file/805509/BNE-2021.pdf.

M. Shirinbakhsh and L. D. Harvey. Net-zero energy buildings: The influence of definition on greenhouse gas emissions. *Energy and Buildings*, 247:111118, 2021.

J. Skwiot. Site vs Source Energy, 11 2021. URL https://www.archtoolbox.com/site-vs-source-energy/.

P. Torcellini, S. Pless, M. Deru, and D. Crawley. Zero energy buildings: a critical look at the definition. Technical report, National Renewable Energy Lab.(NREL), Golden, CO (United States), 2006a.

P. Torcellini, S. Pless, M. Deru, B. Griffith, N. Long, and R. Judkoff. Lessons learned from case studies of six high-performance buildings. Technical report, National Renewable Energy Lab.(NREL), Golden, CO (United States), 2006b.

UNAM. *Disposiciones en Materia de Construcción Sustentable*. PhD thesis, Instituto de Ecología, 2017.

UNAM. Calendarios escolares, 2022. URL https://www.dgae.unam.mx/calendarios_escolares.html.

United Nations. Objetivos de Desarrollo Sostenible, 9 2015. URL https://www.un.org/sustainabledevelopment/es/objetivos-de-desarrollo-sostenible/.

U.S. Department of Energy. Engineering Reference. Technical report, 3 2022. URL https://energyplus.net/assets/nrel_custom/pdfs/pdfs_v22.1.0/EngineeringReference.pdf.

A. O. Velázco Ruíz. *Análisis de los efectos ambientales, energéticos y económicos entre un modelo de construcción sustentable contra uno convencional en Querétaro.* PhD thesis, National Autonomous University of Mexico (UNAM), 2021.

Venture Well. Equipment and Lighting Loads, 2018. URL https://sustainabilityworkshop.venturewell.org/buildings/equipment-and-lighting-loads.html.

Washington State Department of Commerce. Measuring Gross Floor Area. Technical report, 10 2021. URL https://www.commerce.wa.gov/growing-the-economy/energy/buildings/clean-buildings-performance-standard/.

C. K. Wilkins and M. H. Hosni. Plug load design factors. *Ashrae Journal*, 53(5):30, 2011.

World Health Organization. Combined or multiple exposure to health stressors in indoor built environments: an evidence-based review prepared for the who training workshop "multiple environmental exposures and risks": 16–18 october 2013, bonn, germany. 2014.