ISBN: 978-628-95207-8-1. ISSN: 2414-6390. Digital Object Identifier: 10.18687/LACCEI2024.1.1.1770

In situ Net Electricity Balance Analysis at Different Time Spans: Case of an Existing Residential Building in Tropical Climate

Brunilda Pérez, Engineer[1], Katherine Chung-Camargo, M.Sc.[1], Patricia Hung, M.Sc.[1] and Miguel Chen Austin, Ph.D.[1,2,3,*]
[1]Research Group Energy and Comfort in Bioclimatic Buildings (ECEB), Faculty of Mechanical Engineering, Universidad Tecnológica de Panamá, Ciudad de Panamá, Panamá, [brunilda.perez, katherine.chung, miguel.chen]@utp.ac.pa, patricia.hung@chi.com.pa
[2]Centro de Estudios Multidisciplinario en Ciencias, Ingeniería y Tecnología (CEMCIT-AIP), Ciudad de Panamá, Panamá
[3]Sistema Nacional de Investigación (SNI), Ciudad del Saber, Panamá.
*Corresponding author: miguel.chen@utp.ac.pa

Abstract*– The global need for sustainable solutions underscores the importance of net zero energy buildings (NZEB) that reduce energy consumption and greenhouse gas emissions. The implementation of NZEB varies worldwide due to climate and construction methods. Although the benefits are obvious, according to the literature, only a few tropical countries have established policies that support NZEBs. Promoting NZEBs requires policies that address social and financial aspects and real incentives and measurements. Therefore, the study aims to analyze the net electricity balance at different time intervals through in-situ measurements in an existing residential house in a tropical climate; the selected case study is in Panama City, Panama, a semi-autonomous family residence, which is connected to the national electricity grid and an on-site photovoltaic solar generation system. The data is collected through an Emporia measurement device, model VUE Gen 2, with a minimum granularity of one second. Consumption and generation data are analyzed to verify how achievable the NZEB concept is at different periods (annual, monthly, daily, and hourly). The feasibility of achieving the net electricity balance in the other time intervals presented to achieve NZEB for the tropical climate of Panama is evidenced.

Keywords*-- Existing Residential Building, In situ, Net Electricity Balance, Time span, Tropical Climate.

I. INTRODUCTION

Net zero energy buildings (NZEB) achieve high performance by meeting reduced energy consumption through on-site renewable energy sources. These types of facilities are aligned with Sustainable Development Goals (SDGs) 7, "Affordable and Clean Energy," and 11, "Sustainable Cities and Communities," thus contributing to the promotion of more sustainable urban practices and equitable access to clean energy. "On-site" refers to renewable energy sources in, on, under, or near the building. This approach is a key element in the design and operation of these buildings.

Renewable energy generation and self-consumption, primarily through photovoltaic systems, can often experience a time lag. The case study is connected to the PV system and national grid to address this situation. This configuration allows the exchange of energy to compensate for periods of low photovoltaic generation and, when surpluses occur, discharge to the national grid [1].

In Panama, a procedure is established for the self-consumption of new, renewable, and clean energies, where customers of distribution companies can satisfy their electricity demand by installing generation plants to reduce their consumption from the National Interconnected System. Those who decide to interconnect to the national grid to improve their dependence on their isolated system must follow this procedure. In addition, they can sell the surplus energy generated to the electricity distribution company. Customers who opt for this procedure will not be able to participate in the occasional market or the wholesale electricity market contract market, nor will they be able to sell energy to third parties. In addition, they may not divide their electricity load into different accounts for the same farm or related properties [2].

The acquisition of the plant and equipment is at the customer's discretion; however, energy sale agreements between the equipment suppliers and the customer are not allowed since this activity is exclusive to the distribution companies [2].

According to their installed capacity, there are three types of facilities: generation plants of up to 500 kW, generation plants of more than 500 kW and up to 2500 kW, and generation plants of more than 2500 kW. For each type of facility, specific requirements are established. In the case of photovoltaic generation plants, the installed capacity refers to the direct current power before the inverter and the alternating current power after the inverter. To consider the effects on the National Interconnected System or Isolated System, as well as the limits established in this procedure, the power delivered after the inverter is considered. The generation plants must install an exclusive electric meter that registers all the energy produced by the plant, with an accuracy of +/- 2% or better, at the customer's expense. On the other hand, the distribution company must install a bidirectional meter that records the energy inputs and outputs (net metering) to calculate the net balance between the energy consumed by the customer and the energy delivered to the grid by the generation plant [2].

Monthly billing will include the fixed charge, the demand read (kW), and the energy (kWh) resulting from net consumption, i.e., when the kWh consumed by the customer from the grid is greater than the kWh delivered by the customer to the grid. The surplus energy injected into the grid is accumulated as energy credits (kWh) that the customer can use in annual or semi-annual periods, with a maximum limit of 25% according to the analysis of the consumption history established in the interconnection agreement. That is to say, the distribution company will only pay up to 25% of the energy injected into the grid [2].

The development and implementation of NZEB varies worldwide, mainly due to climatic differences. Different building strategies adapted to the specific conditions of each country where the NZEB concept has been adopted can be distinguished [3].

Climate plays a crucial role in energy efficiency systems and energy consumption patterns. Notably, in regions with hot and humid climates, few countries have policies related to net zero energy buildings [4].

In Panama, direct policies have yet to be implemented for NZEBs. However, regarding energy use, Law 69 of October 12, 2012, known as the UREE Law, establishes general guidelines on the rational and efficient use of energy [5]. Regarding sustainable buildings, JTIA Resolution No. 002 of January 13, 2023, which approves the sustainable buildings regulation (RES) for the Republic of Panama [6], has been enacted. This regulation is mandatory; it focuses on the building envelope and does not address internal energy systems or occupant behavior.

NZEBs are part of energy policies in several countries, including new and existing buildings. However, there currently needs to be more consensus on NZEB buildings at the international level. NZEB policy formulation is only one step in the process, as it also requires consideration of social and financial aspects to ensure effective implementation. Developing a roadmap is an effective way to present a strategic and organizational perspective related to NZEBs. This tool is used to provide nations or regions with a clear direction and facilitate detailed planning and design [3].

The NZEB concept establishes a standardized method for calculating net-zero energy, employing energy conversion factors based on the national average source, facilitating accurate and clear assessment of net zero energy performance in buildings.

According to the U.S. Department of Energy (DOE), 2015, in an energy-efficient building, annually, the energy delivered is less than or equal to the renewable energy exported from the site [7]. Because of its broad national acceptance, this definition also allows for compliance with government policies and incentives and various state and municipal initiatives [7]. Although DOE's national averages do not consider regional variations in energy generation and production or differences caused by transmission losses due to project location, they provide a fair and practical formula to promote the global adoption of zero energy buildings [7].

Every phase of the energy cycle, from generation to final consumption, involves energy losses. Efficiency in production and transportation is reflected in the energy source, which is calculated by multiplying the energy at the source of each type of fuel by a particular factor corresponding to that fuel. As an illustration, approximately 3 kWh of total energy is required to produce and deliver 1 kWh to the customer because the efficiency of electric power production and distribution is around 33% [7].

Renewable energy generated on-site is evaluated using these same coefficients, allowing the total energy consumption from avoided sources to be accounted for. These coefficients vary over time as the grid evolves.

Investing in energy efficiency and renewable reduces susceptibility to changes in utility costs and protects possible future carbon taxes or stricter emissions regulations [7].

The NZEB concept can vary depending on its focus, whether net zero site energy, net zero source energy, net zero energy costs, or zero energy emissions. Each definition implies a net-use accounting method and requires renewable energy sources. When the annual balance of primary energy consumption equals zero (0 kWh m^{-2} y^{-1}), a significant exchange of on-site energy generation with the grid is usually observed [3].

The European Energy Performance of Buildings Directive (EPBD) indicates the annual balance period, which refers to the interval during which the calculation of the building is carried out to demonstrate when it reaches its break-even point.

According to EPBD 2010/31 EU, the member state's practical implementation of the near zero energy building (nZEB) definition should reflect specific national, regional, or local conditions. This implies the incorporation of a numerical indicator expressing primary energy use in kWh/m^2 per year. The factors used to calculate primary energy use may be based on national or regional annual average values [8].

The European Union has established that, as of 2021, all new buildings must meet at least nZEB consumption, as set by the EPBD. Furthermore, each member state establishes the national criteria for the nZEB standard based on the general indications set by the directive [9].

The balancing period may vary; the commonly used is annual, but some studies use seasonal or monthly balancing, while in other cases, the analysis is performed by life cycle [8].

Regarding the energy exchange of buildings with the grid, few studies claim that establishing an annual energy balance is adequate when covering operational circumstances, considering seasonal or climatic conditions. Likewise, it is known that considering a smaller time step would imply a much more demanding and costly design. The energy self-sufficiency of NZEBs depends on climatic conditions that are different throughout the year and cannot be programmed so that energy production may vary from one month to another; for this reason, self-sufficiency may be affected by the time span selected for the energy balance [1].

Both life cycle and daily balance are less used, the latter because it is more difficult to achieve since renewable energy production would be required to cover the demand of buildings for photovoltaic energy in winter for its part, considering the life cycle energy balance can be complex when predicting changes in the energy performance of the building during its lifetime. The widely accepted energy balance period is annual, as energy use can vary from year to year for various reasons, including changes in the number of occupants, changes in building use, and climate change [8].

However, more is needed to characterize the energy flows in a building at zero net point; it is necessary to know the interactions that the building has with the energy networks [10].

Analyzing discrepancies between energy generation and consumption is necessary by applying energy balances based on time intervals shorter than the year. It can be shown that employing a monthly rather than annual energy balance can boost building energy performance by promoting energy self-sufficiency and reducing withdrawals from the national power grid [1].

About the energy balance, the literature evidence two predominant approaches: i) The balance between building loads and renewable generation (load/generation), and ii) The balance between energy delivered to the building and energy injected into the grid (import/export). The first is the most commonly used in the studies analyzed. A fundamental reason for this is that it is more suitable for integration into existing building codes, which usually contemplate calculating the building's energy load and the energy generated by renewable sources as key indicators for building design and energy labeling. Despite this, the latter offers a more comprehensive view, encompassing the interactions between the building and the energy network. This approach allows for more efficient control during operation by measuring the interactions between the building and the power grid once the building is occupied, after design and construction [8].

The purpose of a building is to provide a comfortable and protective indoor space against outdoor conditions. Various climatic parameters, such as temperature, solar radiation, wind direction and speed, and humidity, influence building energy consumption. Also, building-related factors include location, envelope, shape, wall color, window-to-wall ratio and glazing, building systems and services, occupant behavior, and socioeconomic and legal characteristics. Consequently, owners can save energy by considering and improving building-related aspects [11]. Concerning the energy balance, a near zero energy building (nZEB) can become a net zero energy building (NZEB) or a plus zero energy building (PlusZEB) [1].

In Central America and the Caribbean, the region's climatic conditions favor implementing this type of construction, especially considering the solar incidence characteristic of its tropical climate. Despite the growing interest in this type of construction, its adoption is still at an early stage. Among the reasons that stand out are the need for more sufficient information about the implementation in tropical climates, the limited number of projects executed or under execution, and the uncertainty regarding the associated costs.

A detailed understanding and accurate assessment of the net electricity balance in a tropical environment for an existing residential house is crucial to inform and improve energy efficiency practices. This study seeks to provide a comprehensive view of the electricity dynamics over time under tropical conditions.

Therefore, our focus is on analyzing the net electricity balance at different time intervals (Annual, Monthly, Daily, and Hourly) through on-site measurements in an existing residential house in the tropical climate of Panama City, Panama. This analysis is based on the research question: how does the net electricity balance vary in different time lapses for an existing residential house in a tropical climate, according to an in-situ analysis?

This study does not consider the use of liquefied petroleum gas (LPG) in the residence, nor does it work in terms of primary energy. However, the energy factors used in Panama for the latter have the same value for electricity consumed and generated, a key aspect to keep in mind while interpreting our results.

II. METHODOLOGY

A. *Description of the residential house*

The selected case study is a semi-autonomous family residence in Panama City, Panama, built in 1989, with the following exact location: 9° 02' 20.5" N 79° 29' 08.4" W. It is interconnected to the national power grid and has on-site renewable electricity generation from a photovoltaic system installed in December 2020; the sizing, assembly, and configuration were done at the owners' discretion. The photovoltaic modules are located on the residence's roof.

The residence receives monthly electricity bills from the electricity distribution company.

Fig 1: Satellite location of the residence is provided by Google Maps.

The installed capacity of the photovoltaic system is 8.88 kW and consists of 24 photovoltaic modules of the PEIMAR brand, model SG370M, each with a capacity of 370 W. The arrangement was carried out: 6 microinverters of 1200 W and 240V AC, manufactured by the APSystem brand, were utilized. These microinverters are equipped with a platform for recording generation data. Each microinverter is connected to 4 photovoltaic modules. Specifically, microinverters 1, 2, and 3 are linked to pass box 1, while microinverters 4, 5, and 6 are connected to pass box 2. These feed-through boxes are interconnected in the feed-in area to the solar plant board, which is linked to the solar plant meter, and there is also a safety cutout. The connection extends to the main panel, switch, and bi-directional meter.

Fig 2: Plan view of the residence, provided by Google Maps.

The residence has three floors, the first with dimensions of 13.045 m wide x 18.405 m long, a second floor of 8.43 m wide x 5.285 m long, and a third floor of 4.30 m wide x 5.285 m long, whose areas are approximately 240 m^2 the first floor, 44.5 m^2 the second floor and 22.7 m^2 the third floor. Thus, the total area of the residence is 307.4 m^2.

Fig 3: Front view of the residence, own source.

It is occupied by five adults of different ages (three men and two women).

The residence has three electrical panels arranged in a cascade configuration. Panel 3 is powered directly from panel 2, while, in turn, panel 2 receives its electrical supply from panel 1. Given this arrangement, we have chosen to focus on electrical panel 1, depicted in Fig 4.

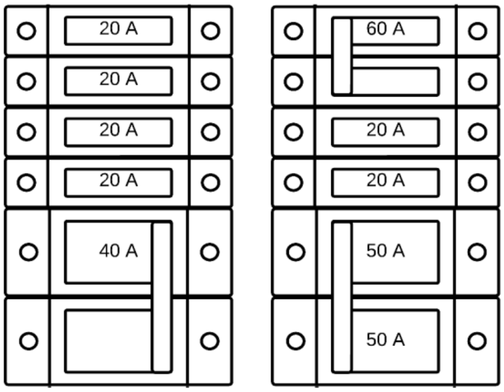

Fig 4: Distribution panel 1 in the residence.

B. Experimental setup and measurement campaigns

This section provides a detailed description of the experimental setup employed in the study, and the measurement campaigns carried out. It addresses aspects such as the boundary limits, the mathematical relationships applied, the operation of the solar PV self-consumption system, and the equipment and methods used to collect relevant data. All this contributes to analyzing and validating the results obtained in the research.

B.1. Boundary system of the case study.

Fig 5, illustrates schematically the configuration of the energy exchange between the distribution company and the residence of the case study.

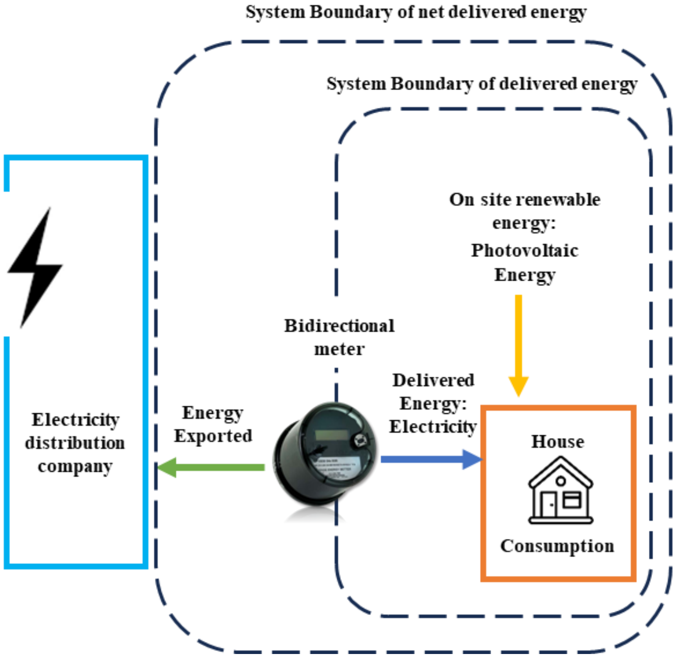

Fig 5: System boundary diagram.

B.2. Mathematical relation

The mathematical relationship (1) governs the system shown in Fig 5 is as follows.

$$C = G - EE + ED \tag{1}$$

The equation represents the energy balance in residence, where the consumption C is calculated as the difference between the energy generated at site G and the energy exported to the national grid EE, adding the energy delivered by the electricity distribution company ED. In other words, consumption is the net result of the energy used in the residence, considering both the local production and the exchange with the power grid and the energy delivered by the distribution company.

If the energy consumed coincides with the power generated (C = G), then both the energy exported and the energy delivered will equal zero (EE and ED = 0).

In the specific case of solar PV, the exported energy is zero during the night.

B.3. Operation of the solar photovoltaic self-consumption system

This section studies the system's interaction with the electrical grid and its capacity to generate and distribute solar energy in response to the home's needs. Fig 6 illustrates an approximation of the operation of a photovoltaic self-consumption system, where the vertical axis represents the power in kW and the horizontal axis represents the hours of the day. Power comes from the grid during the early hours of the day, at night, or at times of insufficient generation. When solar generation is sufficient, electricity is consumed directly by the home. If generation exceeds consumption, the surplus is fed into the national grid. This cycle of energy exchange is repeated throughout the day, adapting to variations in generation and consumption.

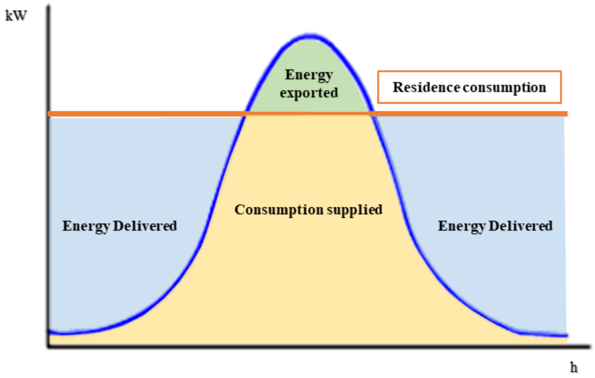

Fig 6: Approximation of the operation of a photovoltaic self-consumption system (energy self-production in blue line). The energy consumption in light blue is covered by energy delivered, and the yellow is covered by self-production; in green color, the energy that can be exported, and the orange line represents the consumption of the residence.

B.4. Measuring instrument

The selected smart energy metering equipment, Emporia VUE Gen 2, was installed, and data was collected. This equipment continuously captures the power consumption distribution of the case study residence.

The system has an energy monitor, WiFi antenna assembly, and two types of current sensors, current transformers (CTs). Two 200 A CTs are located between the electrical panel one and the bidirectional meter, while 50 A sensors are installed in each panel circuit and shown in Figs. 7, 8, 9, and 10.

The metering system connects to the residence's WiFi network to transmit data to a centralized platform, which, thanks to its connection to the cloud, is accessible at any time via a user portal. This configuration not only ensures accurate data collection but also facilitates constant and accessible monitoring for a comprehensive analysis of electricity consumption in the residence.

The metering device provides real-time energy monitoring 24 hours a day, allowing all electrical circuits in the residence to be individually monitored. Data collection at 1-second intervals is essential for detailed and accurate information.

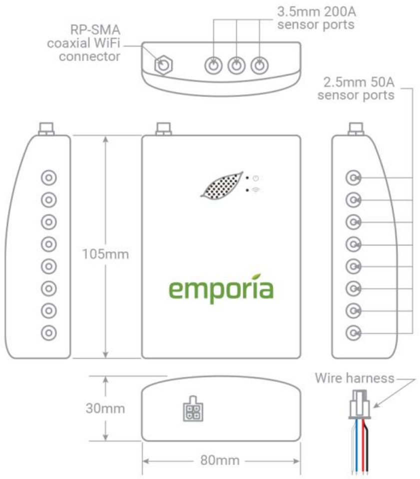

Fig 7: Smart Home Energy Monitor for installation in circuit panels, provided by the product manual.

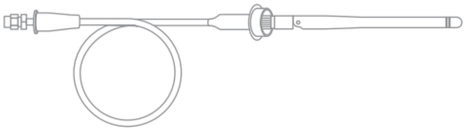

Fig 8: WIFI antenna assembly, provided by the product manual.

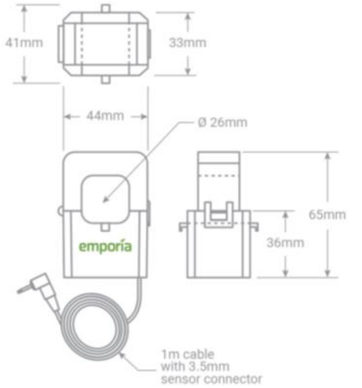

Fig 9: 200 A current sensor, provided by the product manual.

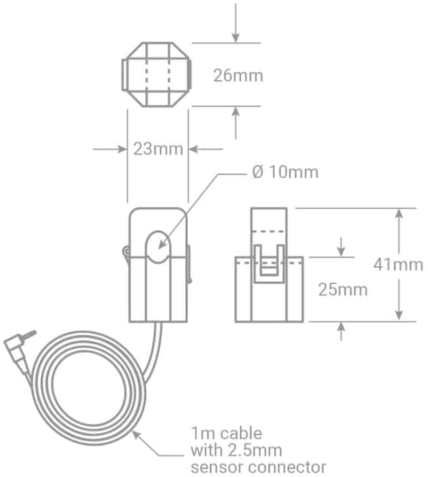

Fig 10: 50 A current sensor, provided by the product manual.

III. RESULTS

A. *Distribution of residential consumption*

Fig 11 presents the residence's electricity consumption by load type from February 18 to April 20, 2024, recorded by the Emporia VUE Gen 2 metering device installed in the electrical distribution panel.

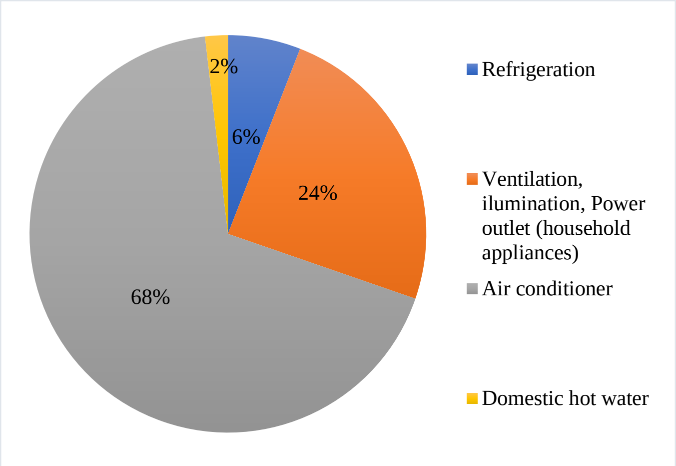

Fig 11: Distribution of electricity consumption in the residence.

The highest consumption in the case study residence is associated with air conditioning, represented in gray, followed by the group formed by lighting, ventilation, and electrical outlets (household appliances), presented in orange. In addition, it can be seen that among the lowest consumptions are cooling, in light blue, and domestic hot water supply, in yellow.

For several reasons, air conditioning tends to be one of the largest energy consumers in residences. First, air conditioning systems tend to run for extended periods, especially in hot climates or during the summer months, which results in higher energy consumption.

B. *Net electricity balance analysis at different time spans*

One of the methods suggested in the literature was chosen to analyze the balance, which contrasts the building's consumption with on-site renewable generation. This analysis was carried out in different periods: annual, monthly, daily, and hourly.

B.1. Annual Analysis

To carry out the annual analysis, we use the electricity billing data provided by the electricity distribution company, adding up each month from January to December to obtain the yearly consumption from 2021 to 2023.

In addition, we consider the annual on-site generation recorded in the APSystems platform for the same period.

Both generation and consumption are a function of the total area of the residence, thus allowing us to have both in kWh/m^2. Meanwhile, the annual balance is calculated as the difference between the energy consumed and generated. As presented in Fig 12.

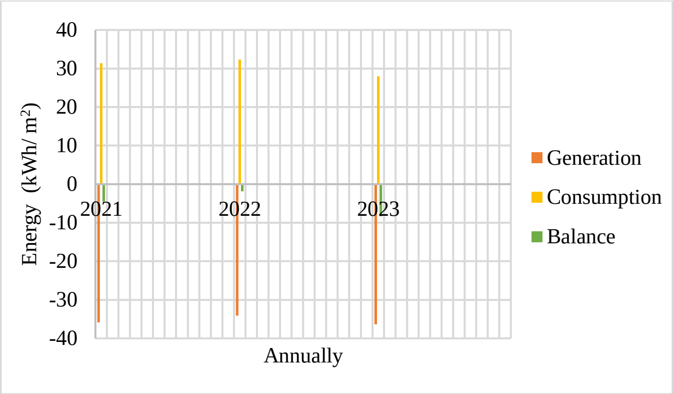

Fig 12: The balance between electricity generated and consumed (from bills) annually.

The annual energy consumed in kWh/m^2 per year is shown in yellow, while the yearly generation in kWh/m^2 per year is shown in orange. On the other hand, the balance is shown in green.

According to the analysis of the data represented in Fig 12, the concept of net zero energy is verified and is fulfilled for all years from 2021 to 2023 since they generate more energy than they consume.

B.2. Monthly Analysis

To conduct the monthly analysis, we used the electricity billing data provided by the electricity distribution company to obtain the monthly consumption from 2021 to 2023. In addition, we consider the monthly on-site generation recorded in the APSystems platform in the same period. Both generation and consumption are a function of the total area of the residence, thus allowing us to have both in kWh/m^2.

Meanwhile, the monthly balance is calculated as the difference between the energy consumed and generated. As presented in Fig 13.

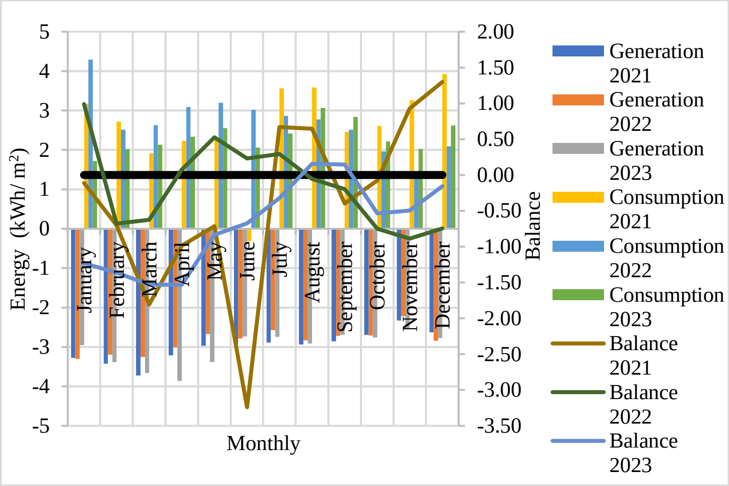

Fig 13: The balance between electricity generated and consumed (from bills) monthly. The black line represents the zero-balance value on the right-hand axis.

Energy generated is shown in bars for 2021 in blue, 2022 in orange, and 2023 in gray. Energy consumed is shown in bars for 2021 in yellow, 2022 in light blue, and 2023 in green; the balance in lines 2021 in brown, 2022 in dark green, and 2023 in light blue. Both consumption and generation are expressed in kWh/m^2. The reading for consumption and generation is done through the primary axis on the left side, and the reading for the balances is done through the secondary axis on the right.

The data represented in Fig 13 are analyzed. It is verified that the concept of zero net energy is met for all the months from 2021 to 2023, given that the zero balance is met in some of the three years. It can be observed that the balance range varies each year; these fluctuations may be related to the behavior of the occupants according to their energy use.

On the other hand, the energy balances for 2021 (brown line) and 2023 (light blue line) show similar behavior, where the building tends to become energy-positive during the first half of the year, unlike what is observed in 2022 (dark green line). This trend is predictable from January to April due to the high intensity of solar radiation in Panama City, as reflected in the energy generation of each year 2021, 2022, and 2023, represented by the blue, orange, and gray bars, respectively. As for energy consumption, it does not follow a clear trend, although it peaks in the middle of the year, except in 2022.

B.3. Daily Analysis

To conduct the daily analysis, we used consumption data obtained using Emporia brand metering equipment, model VUE Gen 2, from December 3, 2023 to January 20, 2024. In addition, we consider the daily on-site generation recorded in the APSystems platform.

The daily consumption is obtained by summing all the quantities consumed throughout the different hours of the day, from 00:00 to 23:00, not the average.

Meanwhile, the daily balance is calculated as the difference between the energy consumed and generated, as presented in Fig 14.

Daily consumption is displayed in blue, while daily generation is shown in orange. The reading is carried out in both variables through the left-hand side axis. The gray line represents the balance; the reading is on the right-hand axis.

According to the analysis of the data in the graph, a net zero energy is verified for all days. It is evident that even with the highest values, the value reaches 0.076, remarkably close to zero.

Although these values are close to zero, there is a trend where energy consumption is higher than energy generation, which presents a high risk of non-compliance with the zero target (the same occurs when expressed in kWh instead of kWh/m^2, as shown in Fig 155). In this time interval, energy consumption and generation per area are so low that the zero target is reached more easily than in longer intervals.

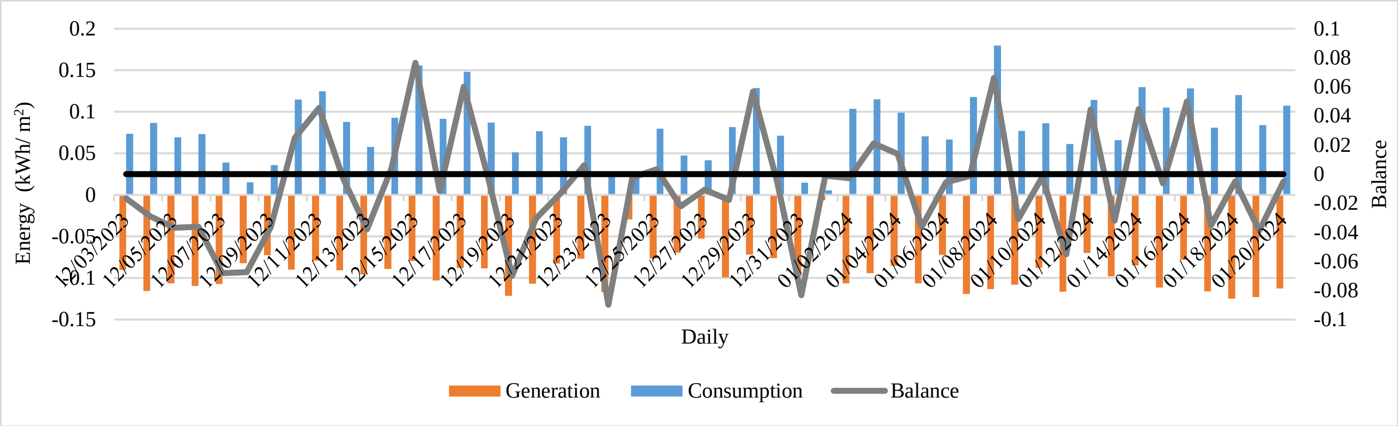

Fig 14: The balance between electricity consumed and generated daily. The zero target is highlighted with a horizontal black line.

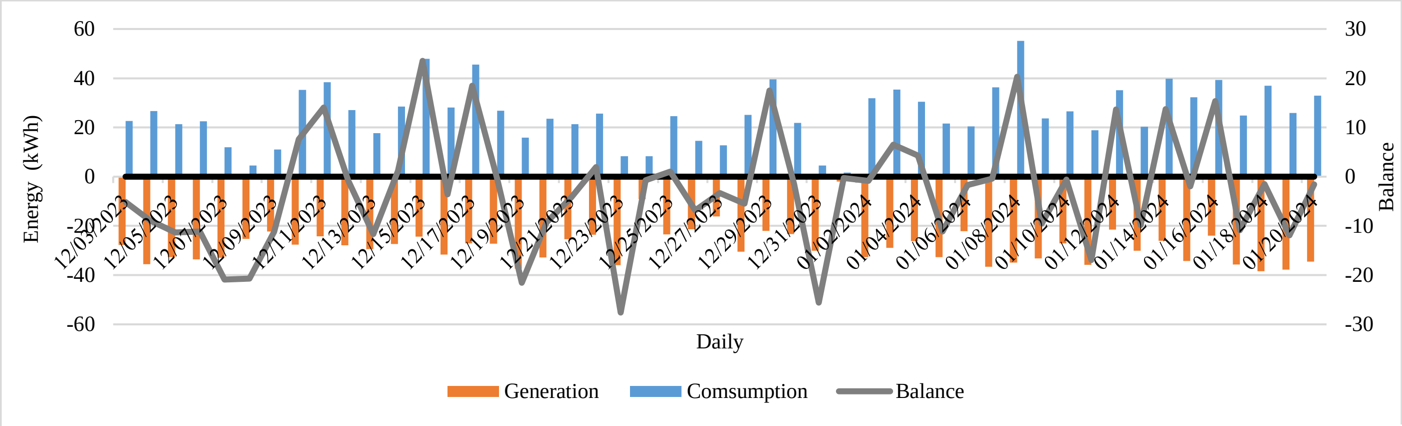

Fig 15: The balance between electricity consumption and generated daily without dividing the area total of the residence. The zero target is highlighted with a horizontal black line.

B.4. Hourly Analysis

To conduct the hourly analysis, we use the consumption data recorded by Emporia brand metering equipment, model VUE Gen 2, from 16:00 on December 2, 2023, to 22:00 on January 21, 2024. In addition, on-site hourly generation recorded in the APSystems platform is considered.

Both consumption and generation are distributed to the total area of the residence, thus being expressed in kWh/m^2.

The hourly balance is calculated as the difference between consumption and generation.

Hourly consumption is shown in blue, while hourly generation is in orange. In both variables, the reading is done through the primary axis. On the other hand, the gray line represents the balance, and the reading is carried out through the secondary axis.

According to the data analysis represented in Fig 16, zero net energy is verified and complies for all hours. It is evident at even in the case of the highest balance, the value reaches 0.01, remarkably close to zero.

As shown in Fig. 17, the behavior of the graph is similar if the analysis is performed without considering the area of the residence.

B.5. Comparative between this study and another study.

Similar studies [1] recognize the influence of the period in which the energy balance is measured on the building's actual ability to supply energy independently.

The accuracy of the annual energy balance for evaluating an NZEB is questioned, as the results indicate that, although the PV surface may meet NZEB targets throughout the year, it only sometimes does so in a monthly balance analysis.

Effective self-sufficiency is mostly affected by unpredictable weather conditions, which vary considerably throughout the year and can result in significant fluctuations in energy production from month to month.

On the other hand, the time lag between self-consumption and energy generated by renewable sources such as solar PV may not be immediately consumed by the user.

Few studies claim that the annual energy balance is adequate to cover operational circumstances when considering seasonal and climatic conditions regarding the energy exchange produced on-site by buildings with the grid.

Shorter periods than the year require a more rigorous design for the analysis.

The selection of the balance period can influence the standard achieved, whether for a nearly zero energy building, a net zero energy building, or a plus zero energy building.

No other works have been found that studies this matter.

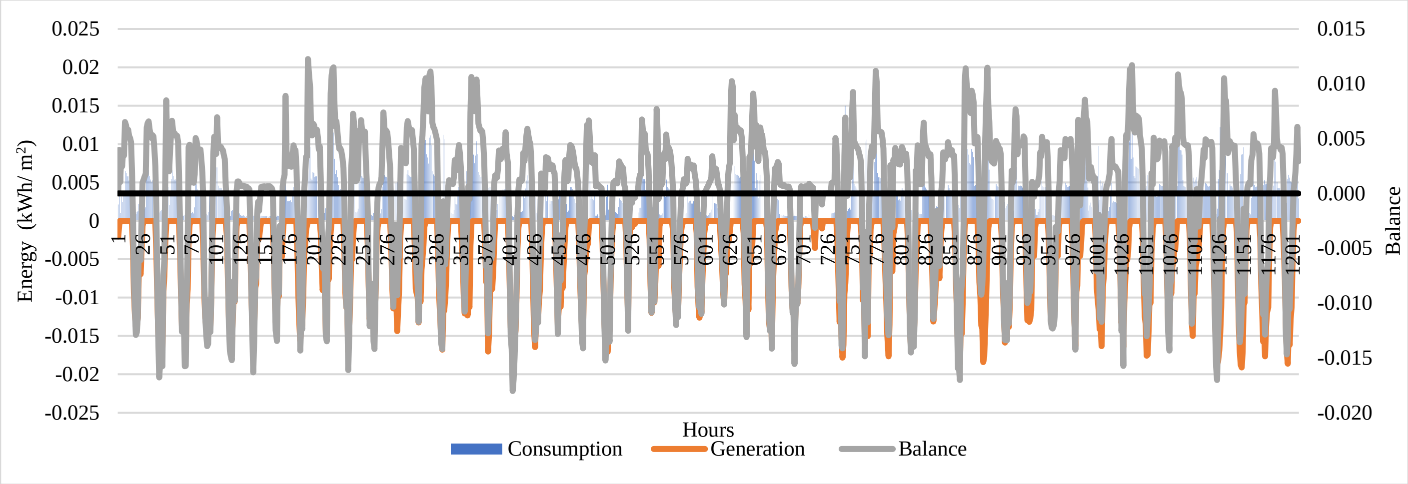

Fig 16: The balance between electrical energy consumed and generated hourly.

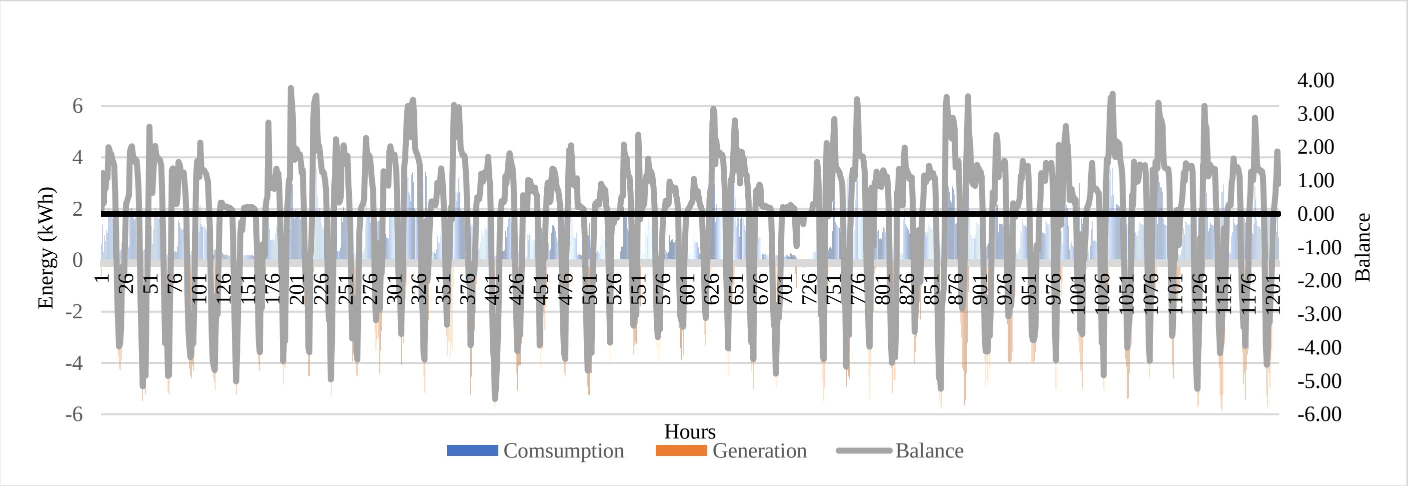

Fig 17: The balance between electrical energy consumed and generated on an hourly basis without dividing the area total of the residence.

IV. CONCLUSIONS

Based on the analysis of the data obtained in this study, the feasibility of achieving the net electricity balance in situ in different time scales to achieve NZEB for a tropical climate, such as that of Panama, is evident. The residence under study maintained a neutral energy balance in annual, monthly, daily, and hourly periods. This result was achieved thanks to an adequate sizing of the photovoltaic system.

It is important to note that, in the face of increased consumption, the solution is something other than installing more solar panels or expanding the capacity of the photovoltaic system. Instead, emphasis is placed on the importance of implementing energy management strategies that focus on occupant behavior. This management can include education on efficient energy use based on specific data and consumption patterns.

This study demonstrates that achieving NZEB is feasible at different time scales; this not only contributes to the energy sustainability of the building but also promotes awareness and responsibility in energy use by the occupants.

ACKNOWLEDGMENT

The authors express their gratitude to the Energy and Comfort in Bioclimatic Buildings Research Group at the Faculty of Mechanical Engineering, Technological University of Panama, for their essential collaboration. Special appreciation to Engineer H. Araúz for providing their residence for the development of this research. This research was funded by the Panamanian Institution Secretaría Nacional de Ciencia, Tecnología e Innovación SENACYT, under the project code FID22-086, the Master of Science in Mechanical Engineering Scholarship, and supported by the Sistema Nacional de Investigación (SNI).

REFERENCES

[1] D. D'Agostino, F. Minelli, M. D'Urso, and F. Minichiello, "Fixed and tracking PV systems for Net Zero Energy Buildings: Comparison between yearly and monthly energy balance," *Renew Energy*, vol. 195, pp. 809–824, Aug. 2022, doi: 10.1016/j.renene.2022.06.046.

[2] Autoridad Nacional de los Servicios Públicos (ASEP), "Procedimiento para Autoconsumo con Fuentes Nuevas, Renovables y Limpias," República de Panamá. [Online]. Available: https://www.asep.gob.pa/wp-content/uploads/COVER_2018/Autoconsumo_Renovables_Limpias/procedimiento_centrales_limpias_2017.pdf

[3] M. C. Austin, K. Chung-Camargo, and D. Mora, "Review of zero energy building concept-definition and developments in latin america: A framework definition for application in Panama," *Energies*, vol. 14, no. 18. MDPI, Sep. 01, 2021. doi: 10.3390/en14185647.

[4] W. Feng *et al.*, "A Review of Net Zero Energy Buildings in Hot and Humid Climates: Experience Learned from 34 Case Study Buildings," 2019.

[5] República de Panamá, *Ley N°. 69 del 12 de octubre de 2012*, no. 27145. 2012. [Online]. Available: https://www.gacetaoficial.gob.pa/pdfTemp/27145_A/GacetaNo_27145a_20121018.pdf

[6] República de Panamá, *Resolución de la JTIA No.002 de 13 de enero de 2023*. 2023. Accessed: Feb. 22, 2024. [Online]. Available: https://www.gacetaoficial.gob.pa/pdfTemp/29726/96966.pdf

[7] ASHRAE, *Achieving Zero Energy Advanced energy Design Guide for Multifamily Building* . 2022.

[8] A. A. W. Hawila, R. Pernetti, C. Pozza, and A. Belleri, "Plus energy building: Operational definition and assessment," *Energy Build*, vol. 265, Jun. 2022, doi: 10.1016/j.enbuild.2022.112069.

[9] "Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings."

[10] I. Sartori, A. Napolitano, and K. Voss, "Net zero energy buildings: A consistent definition framework," *Energy Build*, vol. 48, pp. 220–232, May 2012, doi: 10.1016/j.enbuild.2012.01.032.

[11] M. N. K. De Silva and Y. G. Sandanayake, "Building Energy Consumption Factors: A Literature Review and Future Research Agenda," 2012.