Towards a Definition for Zero Energy Districts in Panama: A Numerical Assessment of Passive and Active Strategies

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Abstract*– Buildings, both in their construction and operation stages, represent a significant percentage of global energy use and carbon dioxide emissions; therefore, it is necessary to implement energy efficiency regulations, both individually and at the urban and city scale. Thus, this research involves a numerical evaluation of bioclimatic and energy solutions to achieve zero energy district (or ZED) in Panama. The research objectives are focused on identifying the factors that most influence energy consumption, systematizing the solutions found, and establishing a preliminary definition of ZED for Panama. By analyzing of a neighborhood (here referred as district) in Chitré, Herrera (base model) and optimizing the variables with the greatest impact on energy consumption, a saving of 31% was found. Finally, the inclusion of solar electricity generation was such that it was possible to cover 100% of the demand, having a positive net balance of 325 kWh/m^{2}y that can be exported to another district or to an intelligent electrical grid system.

Keywords—Dynamic simulation, energy efficiency, tropical climate, zero-energy district

I. INTRODUCTION

For 2017, buildings in their construction and operation phase represented 36% of global final energy use and almost 39% of energy-related carbon dioxide (CO$_2$) emissions [1], which continues to correspond to one of the sectors with the highest contribution to greenhouse gas emissions worldwide. Hence, the need to continue in the search to improve energy efficiency in construction environments and to implement the parameters involved in energy regulations to achieve optimal objectives, both for new and existing structures.

In Panama, through the National Energy Plan 2015-2050, which has as part of its pillars the efficient use of energy, energy safety, and sobriety, it seeks to make more responsible use of the resource and, in turn, contribute to the decarbonization of matrix. The National Energy Secretariat (SNE), and the Ministry of Commerce and Industries (MICI), recognize the need to implement regulations that allow the rapid improvement of energy efficiency at the national level. Therefore various measures have been adopted through Executive Decree 398 of 2013 and Law 69 of 2012 (UREE), for example, where the general guidelines of the national policy for the rational use of energy and the obligation for the equipment distributed in the country, such as air conditioners, refrigerators, lights, and other electrical appliances, to comply with the energy efficiency indices indicated in the technical specifications.

In 2019, the Technical Engineering and Architecture Board (JTIA) approved the Mandatory Sustainable Building Regulations, which seeks to design and build buildings with savings of up to 20% in electricity consumption by including solutions architectural passives.

The search for improvement in energy efficiency in buildings is also linked to the SDGs (Sustainable Development Goals). As a United Nations member, Panama is responsible for meeting these goals integrated into the 2030 Agenda.

The current state of the art presents several studies involved in reducing inefficient energy consumption and greenhouse gas production, having its main focus on buildings with zero or almost zero consumption. In Europe, the Energy Performance in Buildings Directive (EPBD) introduced the concept of nZEB as a near-zero energy building and made it mandatory for the European Member States as of 2020. A recent study reviewed technologies and strategies used to achieve zero energy buildings and thus reduce environmental impact. Key design factors are presented, among which bioclimatic strategies, the building envelope, thermally activated building systems, the type of windows, and others, such as the use of heat pumps and energy production, were documented [2]. In Panama, there are two studies related to zero consumption [3], [4].

Although zero-consumption technologies at the building scale promise good results, it seeks to take the approach to larger scales. In this way, a better precision in the evaluation of energy performance is possible by taking into account the mutual influence between the urban context and between buildings, using as a basis the same principles and objectives set out in the individual scale [5], [6].

In the case of a near-zero energy district (nZED), it is necessary to arrive at an applicable definition of the concept in the country. A first proposal to define the concept of zero energy in communities is found in [7], where it is argued that an nZED reduces energy requirements through efficiency gains, such as the balance of energy for vehicles, thermal energy, and electricity within local renewable resources.

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It is also necessary to systematize the solutions available in the results to make them reproducible, taking as references the new regulations imposed at the national level, such as the Sustainable Construction Guide, for energy saving in buildings approved in 2016, which serves as a tool for the implementation of passive bioclimatic strategies [8].

There is currently no standard methodology for determining a district as zero energy, but it does not indicate a lack of progress in recent publications. The research [9] seeks to accelerate the transformation of the district to achieve nZED, remodel areas with poor thermal insulation, high consumption lighting, and fossil fuel-based heating, based on dynamic energy simulation and selecting representative buildings to extrapolate the results.

The stratification proposed in [5] regarding the energy demand analysis divides the balance of the district into the following determinants:

1) Buildings (passive design, active systems, urban climate, and morphology).

2) Public spaces (lights, infrastructure, landscape, and public use).

3) District-scale energy production (patterns of energy consumption, production, and distribution).

Likewise, the authors in [10] point out that the key criteria that influence the concept of zero energy in districts are design and geometry, urban morphology and location, and finally, energy production and distribution (district cooling and district heating).

On the other hand, the occupants' behavior is very little used in energy modeling on multiple scales. The authors in [11] explain the importance of considering occupants' activity both at the building and district levels and describe useful tools for data capture of urban dynamics, such as sensors, the internet of things, and big data. If a building is considered individually, different results will be obtained to evaluate energy performance, compared to an analysis considering the urban elements that affect energy requirements, obtaining more realistic consumption patterns [5].

Thus, the present research seeks to contribute to local energy goals through the numerical evaluation of an existing residential district, here called district in Panama:

1) This evaluation seeks to reduce the district's total energy consumption through multi-objective optimization by implementing bioclimatic, architectural, and energy solutions (or passive and active strategies).

2) With optimized energy consumption, electricity generation is evaluated by including photovoltaic modules in each building in the district.

3) This evaluation allows for establishing a preliminary reference framework that considers the design and construction under the ZED philosophy.

II. MATERIALS AND METHODS

Identify parameters that influence energy consumption the most at the individual buildings and districts scale, under the Panama climate; systematize bioclimatic, architectural, and energy solutions in residential buildings; and evaluate the inclusion of photovoltaic generation on an urban scale on-site were the three focus objectives of this study. To comply with them, the methodology presented in Fig. 1 was followed.

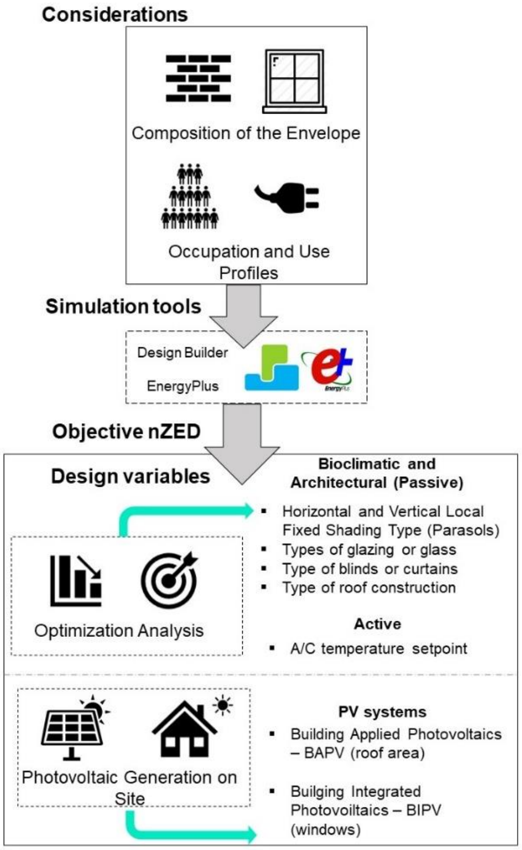

Fig. 1 Schematic of the proposed methodology.

A. *Description of the case study*

The study was carried out using dynamic simulations based on the EnergyPlus calculation engine, which allows the development of a model that considers the thermophysical characteristics of each material used and the dynamics of the site's meteorological conditions. The case study considered a residential district (here called district) under tropical savanna climate conditions (Awi) according to the classification of Köppen-Geiger, located in the province of Herrera, Chitré, Panama, with geographical coordinates 7°58´N, -80°26´ (Fig. 2). The construction period covers from 2016 to 2019 and measures approximately 1.13 hectares wide.

The district 3D model is shown in Fig. 3. In Panama, it is customary to build residential developments with similar houses, and the district consists of 34 houses with 55 m^2 surface, each with the same construction. (within the red polygon in Fig. 2). The interaction between houses is considered in the analysis without accounting for other environmental elements such as vegetation, pavement, and streets.

Fig. 2 Location of the residential development under study (within the red polygon). Google Earth Pro, 2018.

The characterization of the architecture of the district studied was carried out by inspecting the architectural plans of the existing residential complex, where the geometry, orientation, dimensions of the sections, and materials are detailed. Table I shows the construction materials of the houses and the value of their respective transmittance. Similarly, occupancy and energy usage profiles were considered for simulation (Table II).

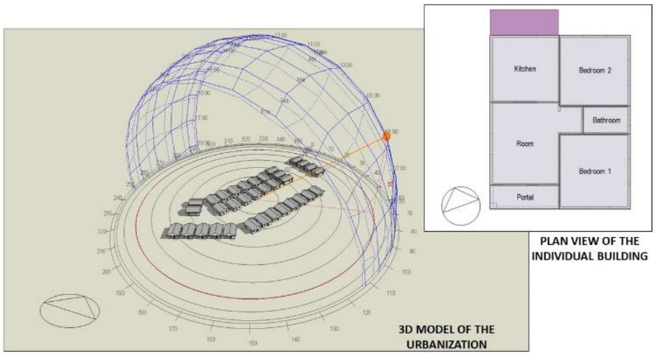

Fig. 3 Three-dimensional model of the existing district studied and plan view of the individual building.

TABLE I
TRANSMITTANCE VALUES BY ENVELOPE COMPOSITION

Envelope elements	U (W/m^2 K)
External walls (mortar, block 100 mm, mortar)	4.009
Windows (3 mm single transparent glass)	3.835
Floor (ceramic and concrete block)	4.659
30° roof (zinc)	7.140

To accounting for areas of use at individual building level, taking as reference occupancy schedules and standard equipment of all houses and assuming that usage for air conditioning 24 hours having a critical energy demand. Note that not all areas include an air conditioning unit, and the operative temperature is used as control.

TABLE II
OCCUPANCY AND ENERGY CONSUMPTION PROFILES IN THE REFERENCE DISTRICT

Description	Area	Profiles	Value
Occupancy	Residence	24/7	5 persons
Natural ventilation	Portal	24/7	Depending on wind characteristics
	Bathroom	24/7	
	Kitchen	7:00-19:00	
Infiltrations	Residence	24/7	0.7 1/h
Lighting	Residence	18:00-23:00	184 W
Split air unit	Room	24/7	COP=3.35, 24°C, 60%Hr
	Bedrooms		
Home electrical equipment	Residence	24/7	630 W

Besides, two different three-dimensional models were made: the first (M1) considered the 34 buildings as building blocks (Fig. 3). The annual simulation of M1 lasted four hours using a computer with 16 Gb of RAM and 3.0 GHz of CPU speed. To perform faster simulation, a second model called M2 (Fig. 4) was created. Using only one representative residential building located in the central part of each row in the district (different orientations and locations), the other houses were drawn as component blocks, where thermal zones are not created. With this model, the simulations for each row lasted 20 minutes with a computer of 8.00 Gb of RAM 2.00 GHz frequency. Accuracy results are shown in the results section.

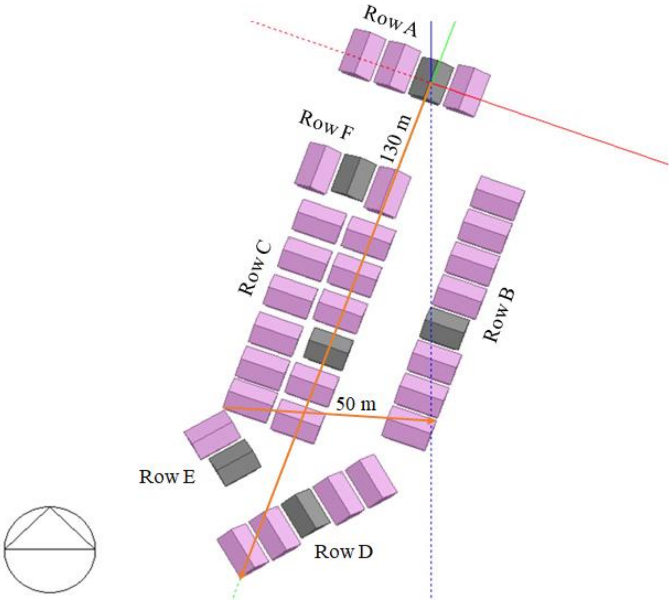

Fig. 4 Reference models using one house per row in the x and y plane.

B. *Assessment of passive and active solutions*

For the evolution of bioclimatic and energy solutions to minimize electricity consumption, an optimization analysis was carried out to identify the best alternatives at the district scale. In this analysis, the minimization of cooling electricity (A/C) and discomfort hours based on the ASHRAE 55 standard with 80% acceptability were considered as objectives.

ASHRAE 55 specifies various combinations of indoor thermal environmental factors and personal factors that will provide acceptable thermal environmental conditions for most people.

For this optimization analysis, a sensitivity analysis was performed to identify relevant parameters considering each of the objectives. Table III shows the design variables chosen based on the passive and active solutions available and the different options for each variable.

The studied include (a) the type of fixed horizontal and vertical shading, (b) glazing type, (c) the type of blinds or curtains, and (d) the type of roof construction. The latter is also known as an architectural solution. The only active solution chosen for an optimization was the temperature value at which the air conditioning is set due to the preliminary results showing the significance of refrigeration consumption.

All the options included were chosen based on availability in the local market and considering standard sustainability criteria. In total, there are 10080 different possible design variables combinations.

TABLE III

DESIGN VARIABLES AND OPTIONS FOR OPTIMIZATION ANALYSIS

Variables	Options
Local shading type (12)	Projection of 0.5 and 1 m with 0.5 and 1 m in overhangs and side fins.
	Overhangs with side fins (0.5 and 1 m projection)
	Projection of 0.5, 1, 1.5 m
	Overhangs of 0.5, 1, 1.5, 2 m
	No shading
Cooling temperature set point (10)	From 23 °C to 28 °C at intervals of 0.5 °C
Glassing type (7)	6mm bronze single
	Clear single of 3 and 6 mm
	Single with 6 mm grey sheet
	Single low emissivity (0.2) clear 6 mm
	Double low emissivity (0.1 and 0.2) clear 6 mm/6 mm air
Type of blinds (4)	None
	High, medium and low reflectivity
Ceiling Construction (3)	Roof with super insulation
	Roof with a value of U x 0.25 W/m^2K
	25 mm mud shingles, with air space of 20 mm and with a ceiling of 5 mm

C. *Incorporation of Photovoltaic generation technologies*

After the optimization analysis is complete, leading to significant energy consumption reduction, we proceed to include photovoltaic generation through: BIPV (Building Integrated Photovoltaics), which are modules that are located in the envelope of a building; as building envelope material and power generation system in traditional buildings, and BAPV (Building Applied Photovoltaics) which are photovoltaic modules usually placed on the roof.

One of the most important points of these types of photovoltaic modules is to recognize their differences because it is known that both play the role same (obtaining solar energy for generation), but in the case of BIPV, usually used in high buildings to take advantage of the absence of shadows and the envelope in general, improving the aesthetics of this and contributing in a certain way as insulators. In the case of BAPV, flat spaces should be used due to their installation system and only meet electrical energy efficiency.

By incorporating these technologies, the total available roof area for the BAPVs was completely covered with the photovoltaic modules with characteristics described later. For the BIPVs, standard glazing with integrated photovoltaic sheets available in the simulator was selected. The BAPV and BIPV were separated into individual generation systems, both as baseload, including system, inverter, and regulator losses.

III. RESULTS ANALYSIS AND DISCUSSION

A. *Energy consumption in the case studied.*

A comparison was made between the results of electricity consumption broken down between the two energy models described in the case study section (M1 and M2). The energy consumption for the use of equipment and lighting was similar in the two models since the same usage schedules were used. However, cooling demand resulted in an average difference of 19.70%, being higher at M1 (Table IV). The results are because M1 takes more aspects of the environment in district, while the second or model, when using component blocks, reduces data and forms a more individualized model (recalling that an analysis was performed per row). To obtain the M2 results, the number of houses per row was multiplied, considering that orientation is one factor that drives the difference in cooling needs since occupancy profile and energy usage are the same.

TABLE IV

COMPARISON BETWEEN M1 AND M2 COOLING CONSUMPTION

Month	Cooling M1 (kWh)	Cooling M2 (kWh)	Percentage (%)
1	25921	20871	19.5
2	23287	18679	19.8
3	26684	21469	19.5
4	26507	21342	19.5
5	27138	21791	19.7
6	24676	19711	20.1
7	26508	21221	19.9
8	26144	20965	19.8
9	24523	19605	20.1
10	25599	20520	19.8
11	23374	18804	19.6
12	26483	21454	19.0
Annual	306843	246432	19.7

These percentages are not considered to have a significant difference. In this way, it is acceptable to use models with representative buildings to reduce the duration and technical resources when simulating. In the following analysis, our reference district an energy caption in for M2.

Fig. 5 shows the resulting energy consumption breakdown in M2, representing the equipment variables (grey), lighting (yellow), and cooling (blue). The highest energy consumption is represented by cooling, i.e., air conditioning, as expected for tropical climates and permanent usage.

These results lead to minimizing the use of energy by cooling, but at the same time minimizing discomfort hours. It can be observed that the average monthly cooling consumption is at similar levels throughout the year, with no apparent tendency to be higher in the dry season (months 12 to 3) than in the rainy season (rest of the months). In addition, this data was compared with average monthly consumption per individual home, which showed higher consumption in the summer months, as expected.

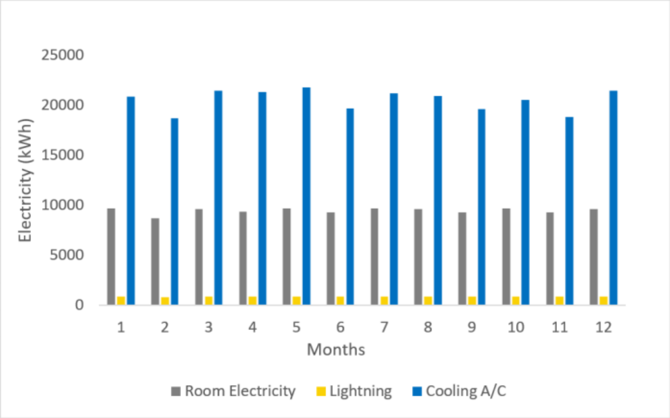

Fig. 5 Energy consumption of the reference district (M2).

B. *Minimizing cooling needs through optimization analysis*

The optimization analysis results based on genetic algorithms allow identifying the adequate configurations, applying an iterative generational analysis process. The algorithm includes the following steps (Fig. 6): encoding variables and design options, random generation of an initial population, file generation, simulation in EnergyPlus of the first solutions and analysis of results, classification of solutions; selection of "parents" (tournament), crossover and mutation, EnergyPlus simulation, the union of parents and offspring, repetition of the process, the established number of iterations and finally the analysis of the best solutions shown on the Pareto front. Table V shows the optimal configuration selected, which was subsequently applied to M2.

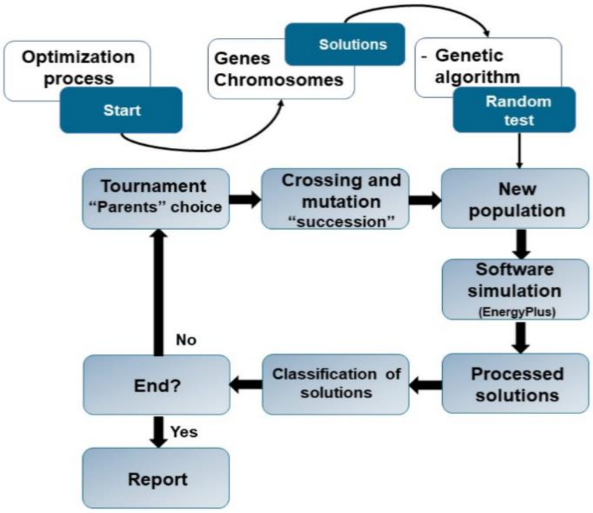

Fig. 6 Flow process of the genetic algorithm for optimization analysis in DesignBuilder.

TABLE V
RESULTED OPTIMAL SOLUTIONS

Design variables	Options
Local shading type	Projection of 1 m with 1 m in overhangs and side fins.
Glassing type	Double light low emissivity (0.1) with 6mm/6mm air.
Type of window blind	None
Roof construction	Roof with super insulation
Cooling temperature set point	28 °C

Concerning the solutions chosen for each bioclimatic design variable: the inclusion of local shading, double glass, and insulation in the roof are consistent with the recommendations reported by other authors [12], [13].

Fig. 7 shows the comparison between the total monthly average energy consumption of the base model (M2), the optimized model (OM), and photovoltaic generation using the BIPV and BAPV systems (PV). Considering the available roof area and 30-degree tilt, a total of 36 solar panels and the system of panels integrated into the windows were included, both per residence. The technical data of the solar implemented are listed below: (1) Active area: 1.68 m^2, (2) Maximum Nominal power: 320 W, (3) Number of cells: 72, (4) Cell type: Polycrystalline silicon, and (5) Panel efficiency: 15%. For the integrated system, the simple method suggested by the simulator (constant efficiency of 15%) was used.

Power generation through the PV system exceeds the electricity demand of the OM in most months and exceeds the demand of the M2. This makes it possible to note that the same district manages to generate locally all the energy it consumes. This highlights the potential it must achieve zero-energy district and even achieve positive energy developments.

It can be seen that the incorporation of optimized bioclimatic and energy strategies based on optimization analysis has reduced energy consumption, achieving savings of 31% per year. This allows concluding about the potential that it had on the site of the district studied to achieve the design and construction of districts at zero energy.

The sensitivity and uncertainty analysis to determine the importance of the chosen design variables revealed that the temperature value at which the air conditioner is set represents the most significant variable.

Finally, it should be clarified that this study does not consider the economic aspects related to BIPV and BAPV systems; only the technical potential is assessed. This allows only to conclude about the potential that is had on the site of the district studied, to achieve the design and construction of districts at zero energy.

Fig. 7 Energy consumption and generation.

C. *Determination of a zero-energy district definition*

It is necessary to determine which energy flows will be included in the energy analysis and how the main factors should be used to calculate energy indicators. Table VI shows the data and values of annual consumption and generation in terms of primary energy, which is obtained by scaling the energy consumption and generation by a national average source factor equivalent to 3.15 from ASHRAE 105. This is a way to determine, express, and compare energy performance in a generic language to be applied to any building. Its purpose is to provide a common basis for informing the energy use of buildings (the form of energy provided and the form of energy expression), comparing design options, and comparing the use of energy (energy used and greenhouse gases produced), all in the building [14].

Fig. 8 represents the results in Table VI, where the primary base energy is the energy consumed by M2 before applying passive and active solutions. Optimized energy is the electrical demand after applying Table V solutions to the model, and finally, the supplied energy delivered from photovoltaic generation, so achieving ZED is more achievable when energy efficiency concepts are applied first. This indicates higher energy production than consumption, with a surplus of 325 kWh/m^2y. Finally, reducing consumption through strategies to increase energy efficiency contributes significantly to achieving zero energy and positive net energy environments.

TABLE VI

NET ENERGY BALANCE FOR PANAMA

Data	Values (kWh/m^2year)
Primary Base Energy (BE)	624.27
Primary Optimized Energy (OE)	428.20
Primary Supplied Energy (SE)	752.97
Net primary energy balance	+324.77
Primary energy exported	324.77

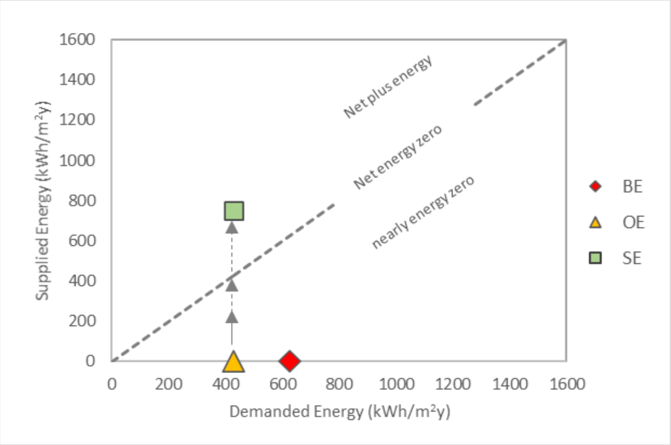

Fig. 8 Graphical representation of the ZED values in the case of study in terms of primary energy.

IV. CONCLUSION

The evaluation of different bioclimatic and energy solutions was carried out through dynamic simulation for existing residential development in the province of Herrera, Panama. This evaluation is focused on reporting the potential of the district under study to be considered as a near-zero or net-zero energy district (or district).

Results indicated that the use of air conditioning at the residential level significantly influences the total electrical energy consumption, where a total annual average energy saving of 30% was obtained by incorporating the optimized solutions. The generation of electrical energy, through the photovoltaic system, managed to exceed the energy consumption of the optimized model by 75%, converting the district as positive energy; that is, the energy production is greater than the consumption. These results show the to achieve zero energy buildings and even near-zero energy districts in Panama. The aforementioned also allows setting more concrete precedents for future national regulations to incorporate the concept of “zero consumption,” taking into account that this philosophy first seeks to reduce consumption as much as possible and then introduce energy generation. Finally, future works may consider aspects that were not considered in this research, such as the effects of vegetation, which influences the through shading factor and economic aspects.

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