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Towards Nearly Zero Energy Buildings in Panama through Low-Consumption Techniques: A Numerical Study

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Abstract. With the aim of promoting Nearly Zero Energy Buildings in Panama, the implementation of low-consumption techniques is studied here via dynamic simulations. For this, a Test model based on the generic construction materials for envelope composition implemented in Panama's standard buildings was developed in DesignBuilder software to evaluate some low-consumption techniques, such as occupancy profile change, free cooling strategies, and modifications of the envelope composition. The envelope composition of an NZEB encountered in Playa Venao, Panama, is also examined. After implementing the low-consumption techniques, the net energy consumption of the Test model remains far from laying within the energy ranges to be considered as an NZEB. However, this numerical study has shown promising results using few low-consumption techniques, which have managed to reduce the energy consumption of the building in 35% with respect to the original energy consumption of the Test model reference.

INTRODUCTION

The current situation has increased calls to action, such as those recently established at the climate conference in Paris (COP21), which seeks to restrict the increase in greenhouse gas emissions by maintaining the global average increase below 2 °C. According to European Policies, by the end of 2020, all new buildings will be nearly zero energy buildings (Directive 2010/31/EU) [1]. With the implementation of the concept of Net-Zero Energy Buildings (NZEB) in Europe for new and existing buildings in the private and public sectors, and for residential and non-residential buildings new regulations have been defined.

The general definition proposed by Torcellini et al. [2] for NZEB is a residential or commercial building with significantly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied by renewable technologies. The concept of a zero-energy building can be defined in some ways, determined by the boundary and the metric. Four of the most used definitions are net zero site energy, net zero source energy, net zero energy costs, and net zero energy emissions. These definitions are different between European countries, there is high variation in NZEB primary energy values being between 20 and 200 kWh m^{-2} y^{-1} in ten countries [3].

The achievement of the NZEB is not linked exclusively to the construction and plant solutions, but is also dependent on the occupant related factors and the consumption of lighting and appliances depending on user behavior becomes prevalent [4].

In NZEB, user behavior has a high impact on the final energy use depending on the correct utilization of passive systems and the operating of active technologies. The indoor comfort (thermal and visual) should be achieved mainly thanks to free resources of energy such as solar radiation and natural ventilation. The role of the occupant in the building performance and in the residents perception of low energy homes is not yet known [5, 6].

Often, a significant discrepancy is reported between predictions or estimates and the actual use of total energy in buildings. The reasons for this difference are primarily known to do more with occupant behavior, than with the building design, according to experts from The Energy Program in Buildings and Communities of the International Energy Agency (IEA-EBC), and the results of the international project Annex 66 [7].

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In Latin America, a few experiences related to NZEB have been studied. In Chile [8], a framework was developed to identified and classified the large variety of performance indicators for NZEB to create a new Chilean Standard for high performance buildings, such as identification of thermal comfort requirements, adopted active systems (including building management systems), reduction of plug-loads, electrification, and impact of appliances and lighting used in the total energy consumption and developed and validated a calculation method for the energy balance.

In Colombia, an NZEB was designed under the methodology cost [9]. Some recommendations were implemented as low energy consumption strategies, such as local construction materials, strategic orientation and location, natural ventilation and lighting, and energy efficient systems.

The first building design in Argentina with NZEB characteristics to evaluate the possibility to build and compare the cost of construction in comparison with traditional technology [10], used The German international standards to select reference values. Among them are: less than 15 kWh m^{-2} y^{-1} in heating and kWh m^{-2} y^{-1} in refrigeration needs, total primary energy demand less than 120 kWh m^{-2} y^{-1} and air renovation less than 0.6/hour. Also, the thickness and thermal transmittances of the external building envelope elements were modified to achieve the Nzeb goal.

Moreover, it is essential to identify the NZEB designs in hot and humid climates as in Panama, where the biggest problem in these areas is humidity that must be taken into account when implementing the different passive strategies [11]. As part of developing countries, Panama has shown strong economic growth over the last decade. According to the World Bank, between 2001 and 2013, its average annual growth rate was 7.2%, more than double the average in Central and South America [12]. Energy consumption in Panama will increase by 188% between 2015 and 2050, according to estimates, if they are not taken measures to reduce consumption and improve energy efficiency [13].

During the last 15 years, Panana has focused on energy footprint changing by creating policies and subsidy programs to reduce energy consumption. Various private and public organizations such as The National Energy Secretary (or SNE in Spanish) and the Ministry of Commerce and Industries and Sectorial Technical Committees have recognized the need to implement measures to improve energy efficiency at the national level [14, 15], following the cravings for developing more efficient buildings and raising awareness among the residential and office sectors. According to the Panamas Sustainable Development Guidelines [16], the following U-values are recommended for educational buildings: 0.80 W m^{-2} K^{-1} for the walls, 0.50 W m^{-2} K^{-1} for the roof and 5.8 W m^{-2} K^{-1} for the windows.

Panama energy building regulations (such as the Sustainable Development Guidelines) does not include a definition for NZEBs. However, around five years ago, in Panama, an NZEB building was built in Venao Beach, Pedasi district part of Los Santos province, under its tropical (hot and climate) climate [17], where the net energy balance of this building lays around 0.72 kWh m^{-2} y^{-1}. Passive and active techniques were implemented, for example, great care was put to the building orientation to promote better natural lighting and cooling, and also, to the exploitation of solar energy through mainly photovoltaic solutions. It is not clear yet if such building was part of the SNE program, but it can be a benchmark to NZEB development in Panama and countries with similar climate conditions. Nevertheless, three areas were identified that must be considered for any building that strives towards net zero site energy use: overall architectural organization (size, orientation, massing, roof forms and location), building envelope (construction type, materials, insulation, air and moisture barriers) and buildings operational cost (efficient systems, appliances, and lighting). The resulting U-values employed in such NZEB are 0.15 W m^{-2} K^{-1} for the walls, 0.3 W m^{-2} K^{-1} for the floor, 0.25 W m^{-2} K^{-1} for the roof and 1.4 W m^{-2} K^{-1} for the windows.

Singapore was taken by the municipality of Panama as an example country to develop Eco Protocolo, a guide to provide recommendations for the design of new buildings to reduce energy consumption, that it is in its final preparation phase to be launched very soon. Like Panama, Singapore has a tropical rainforest climate with relatively uniform temperature and pressure, high humidity, and abundant rainfall. In [18], the authors evaluated an apartment building and landed house through simulation tools to present different optimization scenarios.

Buildings such as houses, offices, among others, are still using “modern architecture” to build them. This “modern architecture” continues to focus on the search for elegant facades and does not place much emphasis on energy consumption for indoor air conditioning. As a solution, building simulation tools are based on heat transfer and thermodynamic equations, and they typically model human actions (e.g., operation of lights, blinds, and windows) employing predefined fixed schedules or rules [19]. Here, the influence of occupants profiles and preferences, for example, family size, ventilation, setpoint temperatures, and management of the heated area, on the indoor conditions are relevant to the final energy usage. For this reason, proper use profiles should be introduced in energy calculations to deliver a more accurate energy performance of buildings [20, 21, 22], considering that the heat and mass flow regimes in buildings depend on several aspects regarding physical and behavioral characteristics [23].

Thus, our study evaluates the performance of the implementation of passive technologies, such as improvement of the thermal insulation of the building envelope, natural ventilation, the thermal inertia of the envelope, in the buildings, in terms of energy and cost, focused on interior comfort. In the same way, the influence of the behavior of the occupants on energy consumption will be evaluated in a preliminary way. Seeking to evaluate different low-consumption and passive technologies through dynamic simulation, aiming to promote nearly zero energy buildings in Panama. The viability of the low-consumption technologies will be evaluated using its influence in the reduction of the initial energy consumption. In the end, it is pretended to suggest what technologies are needed to reduce most the overall energy consumption of the building in question.

METHODOLOGY

In order to assess different low-consumption and passive techniques through dynamic simulation, a Test model is developed in the software DesignBuilder, since it allows for the performing dynamic simulations. For this Test model, generic construction materials implemented in Panama's standard buildings are used. The Technological University of Panama provided these construction materials. A Test model was chosen for this preliminary assessment due to lack of the country energy usage education and bureaucracy issues, the real consumption of this University building was not collected.

Nevertheless, this test model allows for the comparing of the influence of different techniques and the evaluation of which one suits better under Panama's climatic conditions: a humid tropical climate. In this numerical study, the following techniques are assessed: Night free cooling, changes in occupancy profile, and envelope modifications.

Meteorological data are provided by the Hydraulics and Hydrotechnical Research Center (CIHH for its acronym in Spanish) within the Technological University of Panama. These data cover from January 2017 to January 2019. Default meteorological data within DesignBuilder is not used here since it only covers climatic data until 2002.

Moreover, in this study, the Test model helps to explore the thermal behavior of a two-story office building, which is based on the University Campus in Tocumen, Panama city (Fig. 1). This campus is near the Metropolitan Tocumen International Airport (9.05°N, -79.37°W) located at 41 m elevation above sea level. Other data concerning site details are chosen by default, within the corresponding country file.

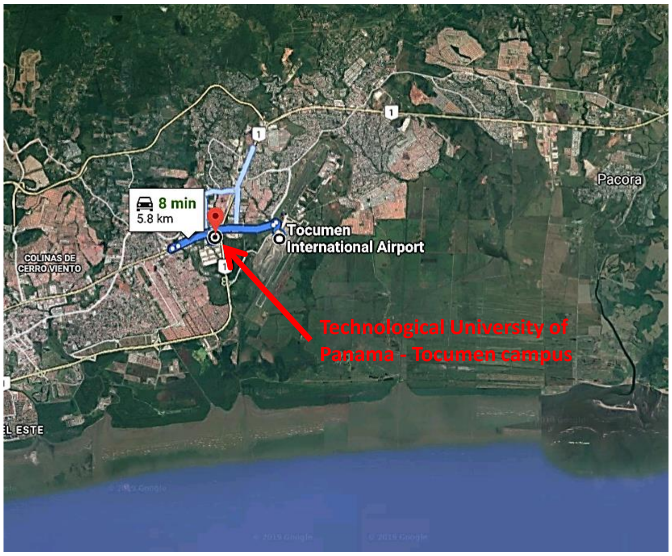

FIGURE 1. Location of Tocumen Campus of the Technological University of Panama [24].

Description of the Test Model

The test model (or reference model) consists of an air-conditioned five-zone two-story building of 109 m^2 each story (Fig. 2). Each facade of the test model has a 48% window to wall ratio (WWR) located, as shown in Fig. 2, with an U-value of 0.49 W m^{-2} K^{-1}. The test model is North oriented (by default). A summary of the U-value of the elements of the envelope composition for the Test model is presented in Table 1.

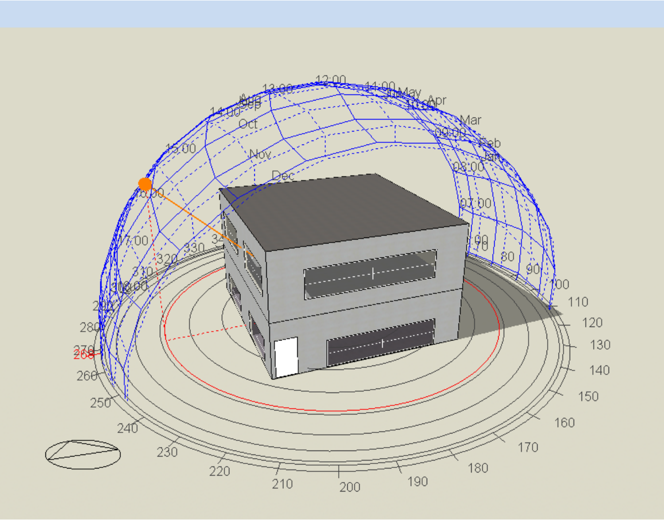

FIGURE 2. Schematic of the test model with sunpath diagram for April, 2th at 15:30.

TABLE 1. Summary of the U-values for each variation of the envelope composition.

	U-value (W m^{-2} K^{-1})		
Envelope elements	**Test model**	**Variation 1***	**Variation 2†**
External walls	3.86	0.15	0.36
Windows	0.49	1.40	0.49
Ground floor	0.25	0.30	0.25
Flat roof	0.25	0.25	0.23

* These values were taken from the NZEB in Playa Venao, Panama [17]

† Envelope of the Test model including insulation layers

External walls consist of a 0.1 m heavyweight concrete block layer among a 0.01 m cement layer for the outermost and innermost layers, with a U-value of 3.86 W m^{-2} K^{-1}. Both floors consist of a multilayer wall (0.25 W m^{-2} K^{-1}) that includes the following from the inner to the outer surface: 0.0254 m of granite, 0.07 m of floor screed, 0.1 m of cast concrete, and 0.1327 m of foam. The flat roof also consists of a multilayer wall (0.25 W m^{-2} K^{-1}), including: 0.013 m of plasterboard, 0.2 m of an air gap, 0.1445 m of MW glass wool in rolls, and 0.01 m of asphalt. It is worth mentioning that thermal bridging is not yet considered in this study.

For the occupancy profiles in the Test model, typical working day occupancy profiles within the University offices are chosen here. These profiles consist of a working schedule from 8:30 to 16:00, from Monday to Saturday. This study also includes active systems in the Test model, which operation is also bound to the working schedule mentioned before. These active systems use an electrical source and include mechanical ventilation, cooling, lighting, computers, and other office equipment. No DHW system is employed, nor holidays are considered. Each active systems has standard characteristics, apart from the cooling system which is a default Fan Coil unit set to a cooling temperature of 25 °C with a setback temperature of 26 °C, and a CoP of 1.8. No auxiliary systems are employed here.

Low-consumption Techniques to Reduce Energy Consumption

Since the higher energy consumption in Panama is due to conditioning indoor air, low consumption solutions are studied here to reduce overall energy consumption.

Case 1: Through Occupancy Profile Modification

The typical working schedule from 8:30 to 16:00 from Monday to Saturday, was modified to a schedule from 8:00 to 12:00 and 13:00 to 16:00, from Monday to Friday. The active system usage is also set to be bound to the modified working schedule. The number of occupants was indirectly estimated by using an occupant density value of 0.1110 people per square meter.

Case 2: Through Free Cooling Strategies

Collected meteorological data shows that the outdoor air reaches acceptable comfort temperature levels during the nighttime with significant wind speed levels, only from 2:00 to 8:00 usually each day. Since the building remains unoccupied during this period, the implementation of a night natural ventilation strategy is studied here. Thus, window openings are set to open when the outdoor air temperature reaches at least more than 2 °C below the indoor air, which is encountered only during the period mentioned above. The airtightness through the model infiltration option is set to 0.7 ach h^{-1} by default and is considered to be a constant rate.

Case 3: Through Envelope Modifications

A first variation of the envelope composition is examined here (named "Case 3.1"), where insulation layers are included within the external walls and roof of the Test model (Table 1, Variation 2 column). The characteristics of the insulation material employed here are taken from commercial insulation materials available in Panama City, Panama. As recommended, a 0.015 m layer of expanded polystyrene is included in the roof composition, and 0.1 m is included in the composition of the external walls; the U-value resulted in 0.23 W m^{-2} K^{-1} and 0.362 W m^{-2} K^{-1}, respectively.

A second variation regarding the WWR is also examined (named "Case 3.2"). This parameter is first reduced from 48% to 40% which reduction is recommended by Panama's National Energy Agency for offices, to observe its influence on the heat gains from solar radiation.

Since an NZEB already exists in Panama [17], a third variation, regarding the U-values of the elements of the envelope composition, is examined here. In principle, this before helps to observe the Test model behavior using experimental-proved U-values that allow achieving an NZEB in a hot and humid region (Table 1, Variation 1 column). This variation (named "Case 4") only includes the modification of the U-value of the elements of the Test model envelope, regardless of the material types used in the Playa Venao NZEB. This NZEB is located 378 km away from the Test model presented in this study (Tocumen campus).

Other Cases

Two other cases are examined here, regarding the building orientation and a combination of the cases presenting best results. For the Test model orientation, five directions are evaluated: 30°, 45°, 90°, 180°, 270°. For the best combination of cases encountered, refer to the results section.

RESULTS ANALYSIS AND DISCUSSION

Impact on the Net Energy Consumption

Since for many countries, the consideration of a building as an NZEB is based on the annual net energy consumption per total surface area, here energy simulation results are performed per year and are presented per surface area. The procedure followed in each dynamic simulation is shown in Fig. 3. Energy simulation resulted for each of the cases described before are presented in Table 2. The Test model using generic building based on the envelope composition employed at the Technological University of Panama yields an annual net energy consumption of 516.64 kWh m^{-2} y^{-1}. The dynamic simulations are based on the operative temperature for indoor condition control.

Table 2 shows that changing the occupancy profile (case 1) from a working schedule of 8 1/2 hours per day (51 hours from Monday to Saturday) to a working schedule of 7 hours per day (35 hours from Monday to Friday) reduces energy consumption by 29%. Such energy consumption reduction is expected since all the active systems are bound to the modified occupancy profile.

The implementation of free cooling strategies through night natural ventilation (case 2) does not influence the net energy consumption of the building significantly. This can be explained by the fact that the wind direction causes thermal buoyancy effects as opposed to wind effects at the window openings on the second story level. This opposition

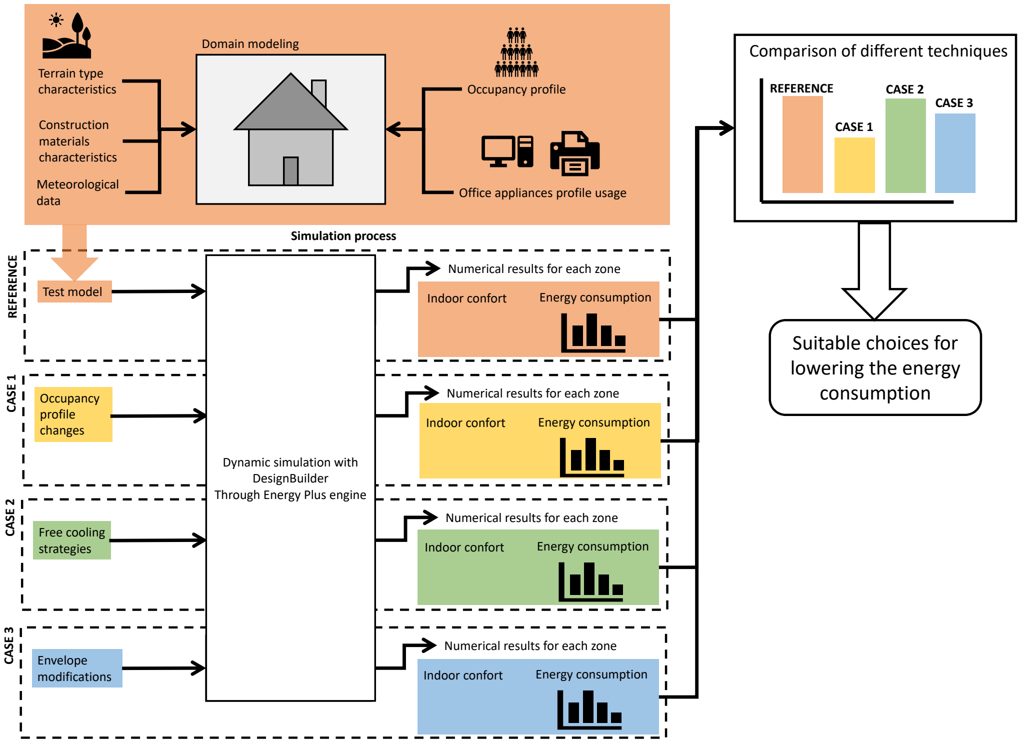

FIGURE 3. Schematic presenting the procedure followed to performed the simulations for the three primary cases.

TABLE 2. Energy consumption results for each case.

Cases	Description	Net energy consumption ($\mathrm{kWh\ m^{-2}\ y^{-1}}$)	Difference (%)
Ref.	Test model	516.64	–
1	Occupancy profiles	366.53	(-)29.05
2	Free cooling	514.17	(-)0.478
3	Envelope modifications:		
	3.1 Adding insulation	439.64	(-)14.90
	3.2 Minimizing WWR	518.27	(+)0.315
4	Playa Venao NZEB	430.83	(-)16.61
5	Building orientation:		
	5.1 For angles 90°, 270°	515.60	(-)0.201
	5.2 For angles 30°, 45°, 180°	Greater than the ref.	–
6	Combining cases 1, 2, 3.1, and 5.1	335.69	(-)35.02

of both effects results in a reduction of the net airflow rate inside the building, which do not allow the indoor air significantly warmer than the outdoor air to exit the building during the active period (2:00 to 8:00).

However, modifying the building envelope composition (case 3) reduces the net energy consumption significantly. Adding insulation layers to the external walls and roof has reduced the energy consumption by 14.90% with respect to the Test model reference. This is also expected since the primary purpose of adding insulation layers is to limit heat penetration through the building envelope. On the contrary, minimizing the WWR has increased energy consumption, which is somewhat surprising since a reduction in solar heat gains are to be expected when reducing the window size (if no window blinds are employed).

Energy results show that the use of the U-values employed in the Playa Venao NZEB, in the Test model, also reduces the net energy consumption significantly in a 16.61% with respect to the Test model reference. These results are encouraging for developing more NZEB in Panama.

For the Test model orientation, rotating the building 90° from a North facing position, and also, rotating it to a 270° position resulted in an energy consumption reduction of 0.2%. It is worth mentioning that the WWR remained the same as for the reference. For the other building orientation angles examined, the energy consumption resulted in being significantly greater than the Test model reference.

After analyzing all the cases implemented before, the combination of some cases showed that the best energy results are encountered when combining cases 1, 2, 3.1, and 5.1. This combination reduces the energy consumption significantly by 35% with respect to the Test model reference.

Impact on the Indoor Comfort

Since not only the energy consumption is essential, the indoor air quality is also examined here, trough a comparison between the test model results and case 6. Figures 4 and 5 show the simulation results for the Test model reference and for case 6, from 01/01 to 04/01. The evaluation of the indoor comfort is based on the value of the operative temperature (Fig. 4 and 5, first graph and third line from top to bottom). The thermal comfort value is set to be 25 °C.

This figure shows the evidence that the modifications (case 6) applied to the Test model influence significantly the thermal behavior of the indoor environment. The fluctuation of the indoor air, operative and radiative temperatures is lower in case 6 with respect to the reference. However, the occupants' discomfort hours are not reduced (Third graphs in Fig. 4 and 5), since the bars show that during the whole hour, the occupants are in discomfort. The bifurcation presented in the indoor air and operative temperature in Fig. 5 first graph, is due to the implementation of case 2, with the modification of the working schedule.

However, even if the relative humidity levels are significantly high in both situations, such levels have allowed the indoor environment to attain constant indoor thermal conditions. Such high levels of relative humidity might not be suitable for office equipment, including computers. In this case, further studies should consider the implementation of humidity control.

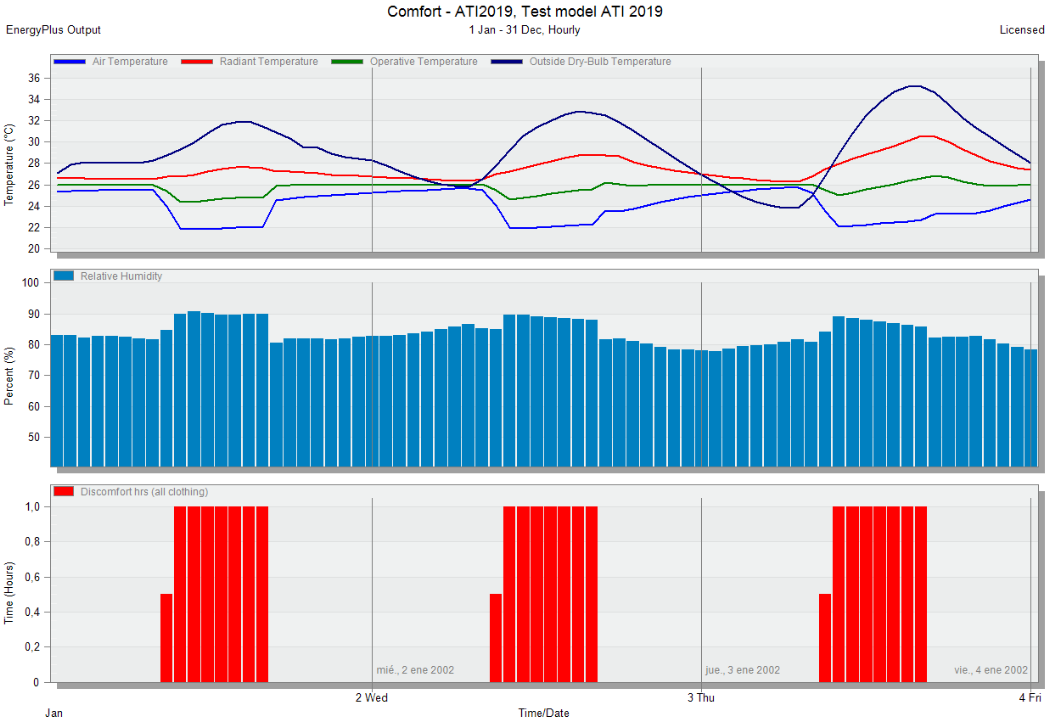

FIGURE 4. Comfort results from simulations for the Test model reference.

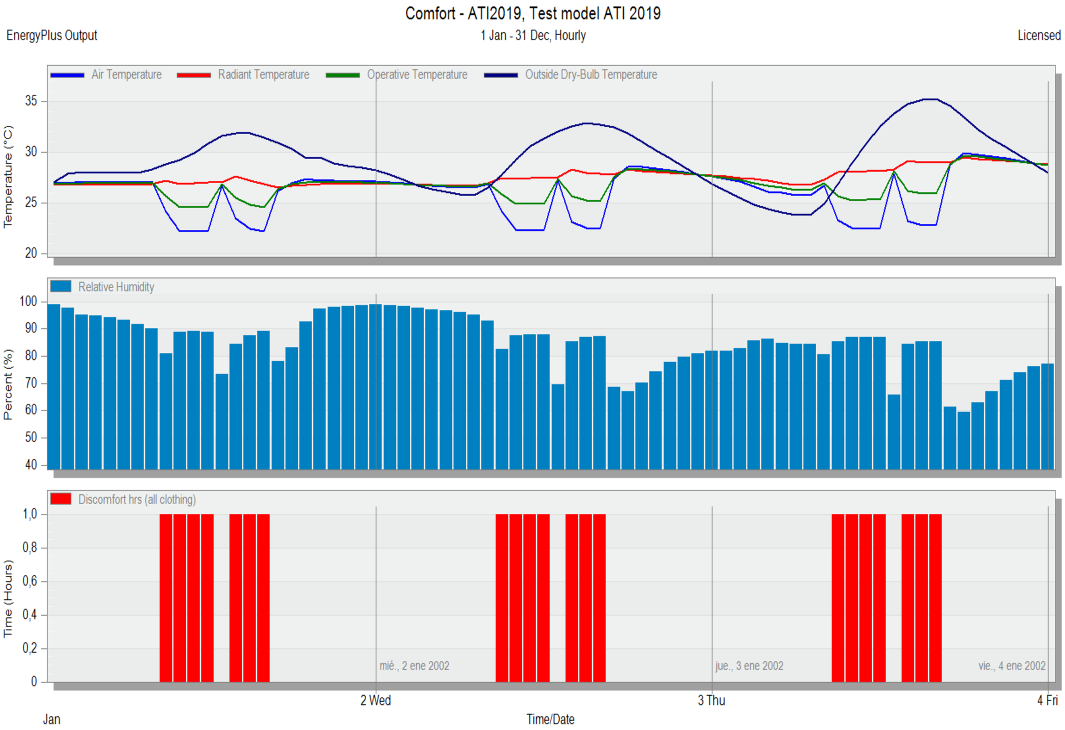

FIGURE 5. Comfort results from simulations for case 6.

CONCLUSIONS AND FUTURE WORK

A Test model based on the generic building characteristics for envelope composition in the Technological University of Panama was developed in DesignBuilder software to evaluate some low-consumption techniques through simulation aiming to change direction towards Net Zero Energy Buildings in Panama.

Even if the building energy consumption after case 6 remains far from laying within the ranges to be considered as an NZEB, this numerical study has shown promising results using few low-consumption techniques, such as occupancy profile modifications, free cooling strategies, envelope modifications, and building orientation.

Nevertheless, further work is needed as a complement to the current work. For instance, the minimization of the WWR might reduce energy consumption significantly when changing window positions or reducing only the size of the windows Sun-oriented. Also, considering albedos contribution in the study might show that windows at the first story should be carefully placed. Moreover, orienting the building to reduced solar heat gains might also yield to reduce wind effects affecting natural ventilation implementation. Comfort conditions are not entirely satisfied in terms of humidity and operative temperature. It is recommended the use of humidity control in further studies.

Moreover, modifications of the building envelope compositions might be better assessed using optimization techniques, with the objective function of minimizing the energy consumption but assuring indoor comfort conditions.

Furthermore, a study dedicated to observing the airflow path when natural ventilation is implemented can bring valuable information about which windows should be opened and which should be kept closed to maximize the free cooling application.

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