paranoá ORIGINAL ARTICLE
TECHNOLOGY, ENVIRONMENT, AND SUSTAINABILITY

2024
v.17, e43115

Energy performance of a nZEB urban commercial building under the influence of a tropical climate and climate change

Desempenho energético de edifício urbano comercial nZEB sob a influência de clima tropical e mudanças climáticas

Rendimiento energético de un edificio urbano comercial nZEB en la influencia del clima tropical y cambio climático

Anderson Azevedo Fraga
Universidade Federal do Espírito Santo; Faculdade de Arquitetura e Urbanismo; Laboratório de Planejamento e Projetos.
Vitória (ES), Brasil.
aaafraga@gmail.com

Layra Ramos Lugão
Universidade Federal do Espírito Santo; Faculdade de Arquitetura e Urbanismo; Laboratório de Planejamento e Projetos.
Vitória (ES), Brasil.

Juliana Silva Almeida Santos *
Universidade Federal do Espírito Santo; Faculdade de Arquitetura e Urbanismo; Programa de Pós-Graduação em Arquitetura e Urbanismo.
Vitória (ES), Brasil.

Cristina Engel de Alvarez
Universidade Federal do Espírito Santo; Faculdade de Arquitetura e Urbanismo; Programa de Pós-Graduação em Arquitetura e Urbanismo.
Vitória (ES), Brasil.

* Autora correspondente.

CRediT

Authors contribution: Conceptualization; Methodology; Data Curation; Visualization: FRAGA, A. A.; LUGÃO, L. R.; SANTOS, J. S. A.; Supervision; Project administration: ALVAREZ, C. E.; Writing – Original Draft; Writing – Review & Editing: FRAGA, A. A.; LUGÃO, L. R.; SANTOS, J. S. A.; ALVAREZ, C. E.

Conflicts of interest: None.

Funding: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES).

Ethical approval: Not applicable.

Use of A.I.: The authors certify that there was no use of artificial intelligence in the preparation of the work.

Editors: Daniel Sant'Ana (Editor-in-Chief), Caio Frederico e Silva (Associate Editor) and Livia Santana (Associate Editor).

Submitted: 29 April 2022 | Accepted: 19 April 2024.

Abstract

Nearly Zero Energy Buildings (nZEB) consist of buildings whose design integrates measures for optimizing energy consumption and renewable energy production systems, sufficient to nearly nullify their energy demand. However, it is known that climate changes can significantly impact the existing energy infrastructure. Therefore, the aim of this article is to analyze the applicability of this concept for urban buildings in tropical cities. Scenarios were simulated using computational models to assess the energy performance of an nZEB commercial building in the city of Vitória (Brazil), under the influence of parameters from urban configuration and climate change projections for 2020, 2050, and 2080. As a result, an increase of 1.17 ºC was observed in the annual average temperature of the external air, and a reduction of 3.85% in photovoltaic energy generation capacity was noted due to the urban heat island effect. In future projections, an increase of up to 23.35% in total consumption and 4.61% in energy production was observed. Furthermore, the cooling system stands out as the main contributor to the building's energy consumption.

Key-words: Performance analysis; Energy efficiency; Photovoltaic energy; Urban Building Energy Modeling (UBEM); Climate change; Future scenarios.

Resumo

Nearly Zero Energy Buildings (nZEB) consistem em edifícios cujo design integra medidas para otimização do consumo energético e sistemas de produção de energia renovável, suficientes para quase anular sua demanda energética. Contudo, sabe-se que as mudanças do clima podem impactar significativamente a infraestrutura energética existente. Nesse sentido, o objetivo deste artigo é apresentar o resultado da pesquisa que consistiu em analisar a aplicabilidade deste conceito para edifícios urbanos em cidades tropicais. Foram simulados cenários com modelos computacionais para a avaliação do desempenho energético de uma edificação comercial nZEB na cidade de Vitória (Brasil), sob a influência de parâmetros da configuração urbana e das mudanças climáticas nas projeções de 2020, 2050 e 2080. Como resultado, foi verificado um incremento de 1,17 ºC na média anual da temperatura do ar externo e redução de 3,85% na capacidade de geração de energia fotovoltaica, devido ao efeito da ilha de calor urbana. Nas projeções futuras, foi observado um aumento de até 23,35% no consumo total e 4,61% na produção de energia. Ademais, o sistema de refrigeração destaca-se como maior responsável pelo consumo energético do edifício.

Palavras-chave: Análise de desempenho; Eficiência energética; Sistemas fotovoltaicos; Geometria e modelagem computacional; Mudança climática; Prospectiva.

Resumen

Nearly Zero Energy Buildings (nZEB) consisten en edificios cuyo diseño integra medidas para optimizar el consumo energético y sistemas de producción de energías renovables, suficientes para casi anular la demanda energética. Sin embargo, se sabe que el cambio climático puede afectar significativamente la infraestructura energética existente. En este sentido, el objetivo de esta investigación fue analizar la aplicabilidad de este concepto a edificios urbanos en ciudades tropicales. Se simularon scenarios con modelos informáticos para evaluar el desempeño energético de un edificio comercial nZEB en la ciudad de Vitória (Brasil), por la influencia de parámetros de configuración urbana y cambio climático en proyecciones para 2020, 2050 e 2080. Como resultado, se verificó un aumento de 1,17 ºC en la temperatura media anual y una reducción de 3,85% en la generación de energía, debido al efecto isla de calor urbana. En las proyecciones futuras, se observó un aumento de hasta un 23,35% en el consumo total de energía y un 4,61% en la producción. Además, el sistema de refrigeración se destaca como el principal responsable del consumo energético del edificio.

Palabras-clave: Evaluación del rendimiento; Eficiencia energética; Energía fotovoltaica; Modelación computacional; Cambio climático; Escenarios futuros.

1 Introduction

The global average temperature continues to rise and the years 2015 to 2020 were the warmest on record since the pre-industrial period. Recent data (referring to the first 9 months) of 2021 indicate that it should also follow this trend (World Meteorological Organization, 2021). Global electricity demand grew by 6% in 2021, driven by a strong economic growth combined with more extreme weather conditions. Likewise, high temperatures and long-lasting heat waves set a record in several countries and contributed to increased demand for air conditioning (International Energy Agency, 2021; 2022).

Although there are great expectations concerning the potential of buildings designed for zero or nearly zero consumption, in order to cope with future adverse environmental effects (Shen; Lior, 2016), climate change research demonstrated that the performance of the nZEBs may be significantly affected in the long term. This downside performance can be explained by variations in the warming up, cooling off processes and the energy consumption of these buildings when submitted to climate conditions that are different from the climate scenario in which they were projected (Sobhani; Shahmoradi; Sajadi, 2020).

Improving buildings' energy performance is an important opportunity to develop the sustainability and resilience of cities (HONG *et al*., 2020). This is particularly needed in emerging markets and developing economies, where rapid urbanization and development require a major investment to ensure zero carbon buildings (International Energy Agency, 2021).

As a result of regulation and standards implementations, Nearly Zero Energy Buildings (nZEB) are buildings implemented with measures for optimization of energy consumption, assisted by renewable energy systems that produce clean energy. This harvested energy is near enough to reach the demand energy needed for their operation (Torcellini, 2006; Kurnitski, 2011). According to Kurnitski *et al*. (2011), some of the main attributes of the Nearly Zero Energy measures are optimized cost and technical performance of primary energy usage, complemented by a percentage of energy harvested from renewable resources. Another very common characteristic of those buildings is the employment of thermal and/or photovoltaic solar energy systems (Moldovan; Visa; Duta, 2016).

Energy planning is important when considering the high initial cost to build a nZEB. It is crucial to consider, particularly in the design phase, the climatic variability caused by future climate change (Cao; Dai; Liu, 2016). Existing methods were combined to simulate this variability, collect data and evaluate the energy performance in the building scale using georeferenced urban context and modified weather files to future scenarios affected by heat island effect. Although some papers already studied these effects linked to buildings and its urban surroundings, particularly applied to the Brazilian context, as Lima, Scalco e Lamberts (2019) shows, this research innovates when it takes an integrated methodology assigned to the energy building need, resuming it near to zero.

Furthermore, related to the adopted method, it is noticeable how positively impacted the workflow is by using only a single-interfaced program, which made possible processing the methodological proceedings and its different stages, as well as compiling the output data from simulation phase. When the interconnection between the built environment, microclimate and climate change are considered, it becomes more evident the building's energy performance. At the same time, if the building is considered as an independent object, the thermodynamic connection between it and the outside environment is compensated, as microclimate, heat flow and the building mass (MAUREE *et al.*, 2019).

According to Reinhart and Cerezo (2016), the introduction of urban context in building thermal energy simulations is indispensable due to increasing proximity between buildings. This closeness is largely caused by the process of densification observed in cities and, by that, the resulting urban environment strongly influences the surrounding buildings and its performance, and vice versa.

Is worth mentioning, apart from what happens in the building modeling process as an isolated object, that the weather file generator selected, CCWorldWeatherGen, captures the dynamic interdependencies among the buildings such as shading effects, heat exchange and solar reflection. According to Hong *et al*. (2020), it also captures the interaction between buildings and the local microclimate such as Urban Heat Island (UHI) effects.

Thus, the aim of this study was to evaluate the viability of the nZEB concept adoption in buildings located in tropical cities, having as methodological basis the assessment of a nZEB commercial building and its energy performance under the influence of a real urban configuration and climate change. The building typology was defined considering that commercial buildings demand a greater amount of energy due to the electrical power that the equipment and systems demand (Conselho Brasileiro de Construção Sustentável, 2015).

2 Methodology

Four methodological steps were established for the development of the research, as follows: (1) characterization of the object of study; (2) delimitation of the scenarios for simulation; (3) thermal energy simulation of the model building; (4) assessment of the energy performance obtained in each scenario.

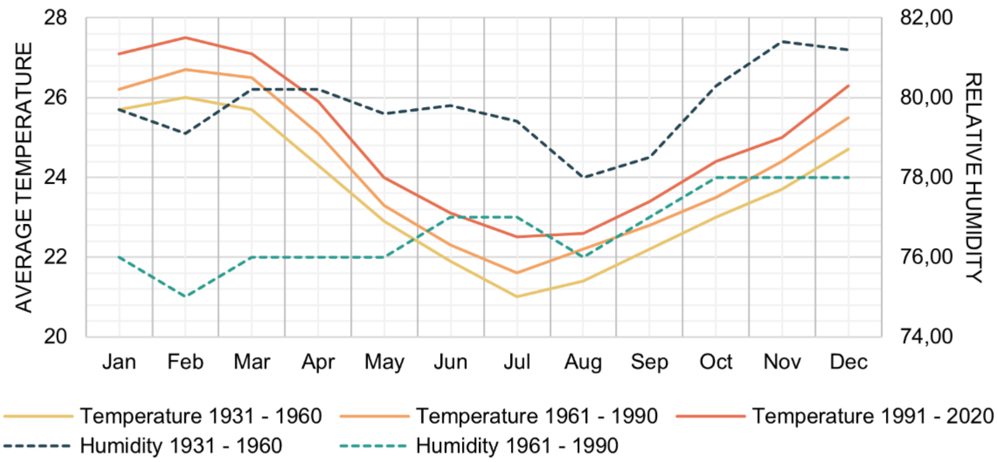
2.1 Case Study

Vitória was chosen for the case study considering its tropical climate, as well as data availability and its relationship with prior studies developed by Fraga (2020). As the capital of the Espírito Santo State, Vitória is in the southwestern region of Brazil, at the geographical coordinates LAT 20°19'20" S and LONG 40°20'17" WGr (Cidade-Brasil, 2020). Respecting the morpho-climatological characteristics, the State of Espírito Santo has two distinct natural regions: the shore, along the coastal region; and the plateau, which originates the mountain area in the territory (Instituto Jones dos Santos Neves, 2011). Vitória's climate is described as Tropical Warm type, Aw, with a transition area type Am (Correa, 2014).

Figure 1 illustrates an increase in the monthly average temperature provided by the National Institute of Meteorology (INMET) over recent years. The data monitored at the station located in the city of Vitória follow the patterns of the World Meteorological Organization (WMO) and are based on consecutive periods of thirty years. The first interval goes from 1931 to 1960; the second goes from 1961 to 1990; and the third one from 1981 to 2010.

The annual average solar potential of the daily total of global solar radiation for Espírito Santo varies between 4.8 and 5.2 kwh/m^2/day. It is observed that these values are superior to the average of European countries such as Germany, France and Spain, which traditionally invest in this niche of energy production. The state has a good amount of solar radiation due to its location and presents favorable conditions for electricity generation from solar energy. In this regard, it is noted that the annual average of solar radiation incident on an inclined plane varies between 5.07 and 5.58 kWh/m^2/day (Agência de Serviços Públicos de Energia do Estado do Espírito Santo, 2013).

Figure 1: Monthly average temperatures (°C) and humidity (%) registered by the Vitória Station of the INMET from 1931 to 2020.



Source: INMET (2020).

The urban section selected represents the densely populated areas predominantly used for commercial activities, with vertical buildings, located near busy streets with intense flows and next to the financial center of the capital (Figure 2). Inside this section, a commercial building was proposed, with the characteristics of office buildings found in Vitória and in other Brazilian cities as well. The computational model of the evaluated building is based on the typological studies of the region, performing the function of the study object in order to establish the energy performance in the defined climate and urban conditions. Besides the constructive characteristics, the model was optimized in order to result in a balanced relation between consumption and energy production.

Figure 2: Selected urban area and its geometric model.

Source: adapted from Google Earth (2022).

It is observed that the constructive specifications were delimited aiming for the best performance possible considering the climate of the region and the generic typology configuration of the model. Thus, the variables of the following parameters were modified: total percentage of the facade opening; cooling system; thermal transmittance of the roof; measures to reduce the electric charge – lighting; and measures to reduce the electric charge – equipment. In Table 1 the main constructive characteristics of the model building are displayed.

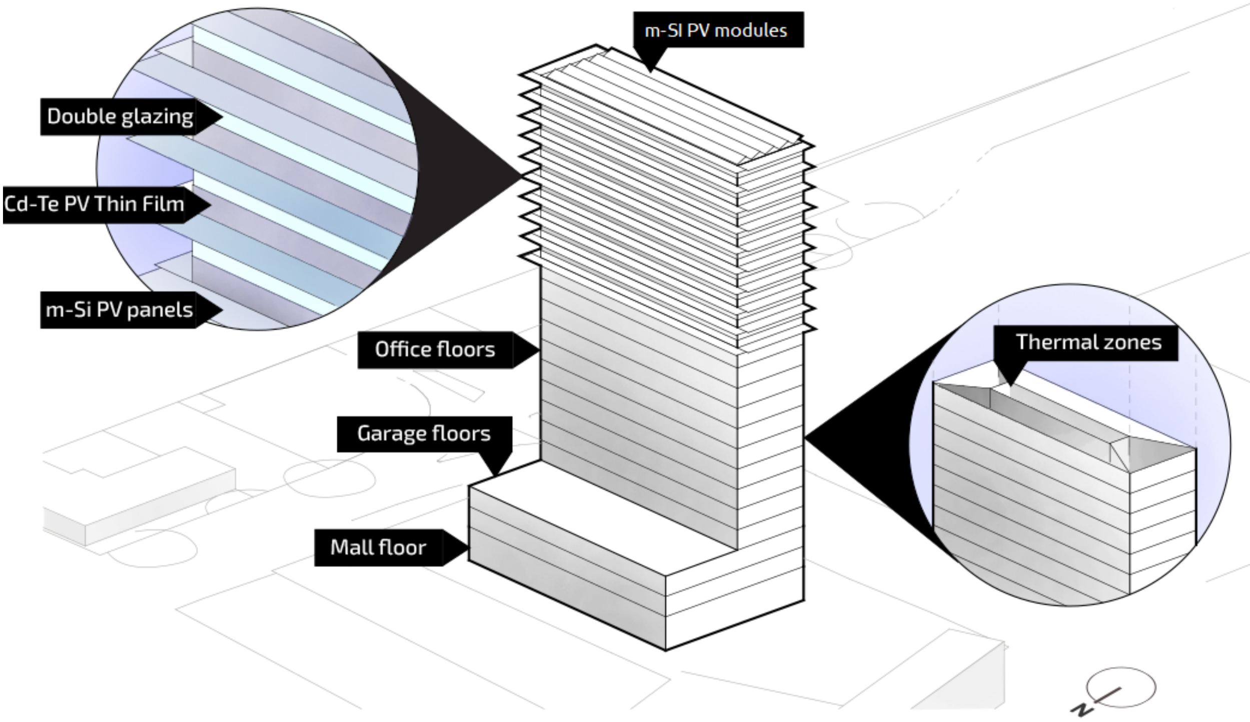
Table 1: Constructive Specifications of the evaluated building.

Item	Type	Characterization
1	Solar orientation	South
2	Glass	Monolithic, 6 mm thick, low emissivity – SHGC 0.16; U-value 3.608 (CB3E, 2014)
3	Window-to-wall Ratio - WWR	30% on the reference floor plans and 50% for the shops on the first floor (CB3E, 2014)
4	Cooling System	VRF – COP 5.5 (INMETRO, 2013; CB3E, 2014)
5	Thermal transmittance of the walls	Wall composed of internal plastering mortar (2.5 cm), concrete block (14 cm x 19 cm x 39 cm), external plastering mortar (2.5 cm), polystyrene (8 cm) and aluminum composite material – U= 0.32; R=3.12 (INMETRO, 2013)
6	Thermal transmittance of the roof	Roof composed of precast concrete slabs (12 cm – concrete (4 cm), EPS (7 cm), mortar (1 cm), air chamber (~5 cm), metal roof tile (0.1 cm), polyurethane (4 cm) and metal roof tile (0.1 cm) - U=0,488 (INMETRO, 2013)
7	Solar Protection	100 cm, protecting the internal spaces from solar radiation until 3 pm
8	Measures for the reduction of the electric charge: lighting	Implementation of more efficient bulbs (LED) and presence detector sensors for the rooms – reductions of 4.0 W/m^2 in offices and 3.0 W/m^2 in the hallways, shops and parking lots (INMETRO, 2013; ASHRAE, 2019)
9	Measures for the reduction of the electric charge: equipment	Implementation of equipment with Energy Efficiency Certificate “A” and implementation of measures for sensible use of equipment – reductions of 6.8 W/m^2 in offices and 2.0 W/m^2 in shops (INMETRO, 2013; ASHRAE, 2019)
10	Occupancy	0,3 people/m^2 in stores and 0,02 people/m^2 in offices (CB3E, 2014; ASHRAE, 2017)
11	Air leaking	At stories with 0,000285 m^3/h/m^2 and 0,0003 m^3/h/m^2 in stores at basement (ASHRAE, 2017b)
12	Occupancy pattern	Monday to friday, with 100% occupancy from 9 am to 6 pm e 50% occupancy from noon to 1 pm
13	Setpoint	21 °C to start heating system and 24 °C to start cooling system (ASHRAE, 2017b)

The projected building has a rectangular base with stores on the first floor and two parking floors. Right above that, there is a recessed tower with 19 reference floor plans for offices and an area for horizontal and vertical flow. In order to check these spaces concerning their main volume, five thermal zones were defined for the first floor and the reference floor plan of the towers, with four of them for the facades and the other one centralized referring to the circulation area, as illustrated in Figure 3.

The PV system was proposed as a measure to counterpoint the building energy consumption and rely as a renewable energy resource. This system was configured with monocrystalline silicon (m-Si) photovoltaic modules and inverters were dimensioned along the horizontal surfaces available at the building, as well as photovoltaic thin films of cadmium telluride (Cd-Te) and inverters on the opaque surface areas in the North, East and West facades of the computational model (Figure 3).

Figure 3: Geometric model of the evaluated building.



2.2 Scenarios for Simulation

The scenarios were elaborated for the same building (detailed in item 2.1) under different conditions of climate and surroundings. Concerning the urban space, two conditions were considered: the modeling with and without the interference of the urban environment. Therefore, a simulation (scenario C1) considering the building without surroundings was initially carried out and, in the other scenarios, the allotments, surrounding buildings, pavements and the arboreal elements characteristic of the selected urban section, were selected and added to the model using Geographic Information System (GIS) files available on website's city hall.

Conditions were delimited to the process of climatic characterization, as follows: in the first scenario, the modeling was submitted to the rural weather file of Vitória from the year 2018; in the second scenario, the modeling was submitted to the urban weather file of Vitória from the year 2018; in the third, fourth and fifth scenarios, respectively, the modeling was submitted to the urban climatic projection of Vitória for the years 2020, 2050 and 2080.

There are several mathematical methods to modify a weather file (Lima; Scalco; Lamberts, 2019). For the present study, the computational tool Dragonfly from the Grasshopper was adopted, through its component Urban Weather Generator (UWG), that predicts the canopy-level urban air temperature and humidity from weather data measured in a meteorological station, which is located in a rural area near the study location (Bueno *et al*., 2013).

The output data for the air temperature generated in the UWG, called "morphed temperature", can be used to investigate the effects of the UHI of a determined place, in the energy use profiles of the buildings. It can also be used to evaluate the effects of an UHI in association with the global warming effect originated by the climate change phenomenon (Nakano *et al.*, 2015). In the latter case, it is necessary to combine the UWG with another tool which allows the conversion of the present weather files into future projections.

On the other hand, Nakano *et al*. (2015) used the UWG in association with the tool Climate Change World Weather File Generator for World-Wide Weather Data (CCWorldWeatherGen) to analyze the effects of UHI and of the global warming in a study about urban design at the East Campus of the Massachusetts Institute of Technology (MIT) which aimed to evaluate the urban thermal comfort and the energy consumption.

The methodology used in the research is similar to the one carried out by Nakano *et al*. (2015). With the purpose of creating the urban weather file specific for the analyzed study area, meteorological data from a rural station of Vitória (Brazil) related to the year 2018 were used, which were made available for free at the website of the National Institute of Meteorology - INMET. From these data, the file was created in the format of Energy-Plus Weather file (EPW), named “rural EPW” in the study. Afterwards, the UWG was used to modify the rural EPW aiming at generating a new EPW, called in the study “urban EPW”.

A second procedure was carried out in order to generate future weather files adapted to the climate changes. For this purpose, the software CCWorldWeatherGen was used, which modifies a “current” EPW into a file of future climatic projection in the formats EPW or TMY2. This tool is for free and allows the creation of weather files to any place in the world, considering the scenario of emissions HadCM3 A2 (medium-high) of the IPCC for three distinct time slices: 2020s, 2050s and 2080s (Jentsch *et al.*, 2013).

Through these procedures it was possible to obtain five weather files with distinct characteristics for further use at the thermal energy simulation, which are: the rural EPW, in which the original data of the place where the meteorological station is located were compiled; the urban EPW 1, which is the rural EPW modified from the urban characteristics of the section chosen for the case study; the urban EPW 2, which is the urban EPW 1 adapted to the climatic projection for the year 2020; the urban EPW 3, which is the urban EPW 1 adapted to the climatic projection for the year 2050; and the urban EPW 4 which is the urban EPW 1 adapted to the climatic projection for the year 2080 (Table 2).

Table 2: Scenarios for the thermal energy simulation.

Scenario	Characterization
C1	Isolated building + rural weather file from 2018 (rural EPW)
C2	Building + urban context + urban weather file from 2018 (urban EPW 1)
C3	Building + urban context + urban climatic projection for 2020 (urban EPW 2)
C4	Building + urban context + urban climatic projection for 2050 (urban EPW 3)
C5	Building + urban context + urban climatic projection for 2080 (urban EPW 4)

2.3 Thermal Energy Simulations of The Building

The modeling of the scenarios was carried out by the tridimensional modeling software Rhinoceros (Mcneel & Associates, 2021) with the plugin Grasshopper (GRASSHOPPER3D, 2021) and its associated tools, as the Honeybee and Ladybug, which help with the thermal and energy evaluation of spaces. Among the creation of the geometrical model, the main building structure and its occupancy pattern were configured, and the urban context was inserted as an object of shading. Besides that, the weather data for Vitória were inserted into the system. These data were divided into different files (detailed in item 2.3), which allowed the identification of the local microclimate variations in time intervals.

Regarding the urban section chosen, it was observed the presence of high buildings used for different purposes, such as commercial, residential and institutional. The surrounding buildings' facades are composed of 30 to 50% of glass with Solar Heat-Gain Coefficient (SHGC) of 0.44 and walls with an average value of 0.4 for the albedo. The roofs and the streets have a lower albedo value, while in the streets there are small grass areas and urban woods.

The energy generation system was designed so that the opaque areas available would be used in the building for energy production and to take advantage of the passive strategies for the reduction of consumption. Given the limited solar exposure by the surroundings, the roof and the North, East and West facades were chosen as favorable areas for the implementation of the system. Solar protections for the openings were included to serve both as support for the photovoltaic panels and as protection against solar radiation on the spaces, which also could work to control natural lighting.

The technologies for energy generation which are part of the system are: thin films of cadmium telluride (Cd-Te) installed at the opaque areas of the facade and on the windowsills, with nominal power of 122.5 kWp and efficiency of 17%; and traditional photovoltaic panels, composed of monocrystalline silicon (m-Si), installed at the usable roof area and on the solar protections of the facades, with nominal power of 435 kWp and efficiency of 20.3%. All panels and thin films were separated in 6 modules, connected in parallel to the inverters with an efficiency of 90%.

The modeling of the energy generation system was carried out in two moments. The first consisted in building a computational model itself, without conditioning the thermal zones, only as the basis for the main simulation. In the second moment, which was the main simulation, photovoltaic panels were modeled, with the proportion of 90% between the support frame and the photovoltaic cells, distributed along the surfaces proposed for the system.

3 Results and Discussion

The results of the simulations were presented taking the base values for the comparison of data according to the sequential addition of parameters, as the insertion of the urban context, the future climate alterations and energy generation. These parameters were assessed through the measurement of the dry-bulb temperature and the electric energy consumption of the building.

3.1 Urban Context

In this first simulation (scenario C1), the average dry-bulb annual temperature obtained was 24.40 °C, whereas in scenario C2, in which the simulation incorporated data from the urban context, it observed an increase of 1.17 °C compared to the average of the previous scenario.

In scenario C1, the highest monthly average of the dry-bulb temperature was obtained in December, 26.86 °C, whereas in scenario C2 the peak temperature alternated in March and was 28 °C. In August, the lowest monthly average was obtained in both scenarios. However, in the first, the value was lower than in the second, respectively, 21.69 °C and 23.09 °C. Although the temperature oscillation range was similar in both scenarios (it was detected with a difference of only 0.08 °C), the averages found showed a tendency of external temperature increase in urban precincts (C2).

It is suitable to emphasize that the distance between the buildings resulted in a shading effect, which was not taken into account in the scenario without surroundings (C1) and blocked the direct radiation in different spots of the computational model along the year. This aspect emphasizes the need to take into consideration the modifications caused by the surroundings in order to obtain more reliable analyses of the building itself. For that matter, the Urban Building Energy Modeling (UBEM) is an important tool for the development of the studies about the energy performance of buildings.

On the assumption that there are changes of value when comparing the results between the simulation of the isolated building to the other scenarios with more buildings, the configuration of the present urban scenario points to a future with high average temperatures.

3.2 Climate Scenarios

The weather files adapted for the scenario of emissions HadCM3 A2 in the years 2020, 2050 and 2080 were substituted sequentially during the simulation. Thus, it was possible to observe an increase in the annual average dry-bulb temperature of 2.74%, 6.21% and 11.10%, respectively for the future years selected. These variations took place homogeneously, with a gradual increase every year, which varied from 0.41 °C to 1.75 °C, confirming the maximum difference of temperature found by Guarda *et al*. (2020) between the years 2020 and 2080.

Figure 4: Temperature variations for the year 2018 (Rural and Urban), 2020, 2050 and 2080.

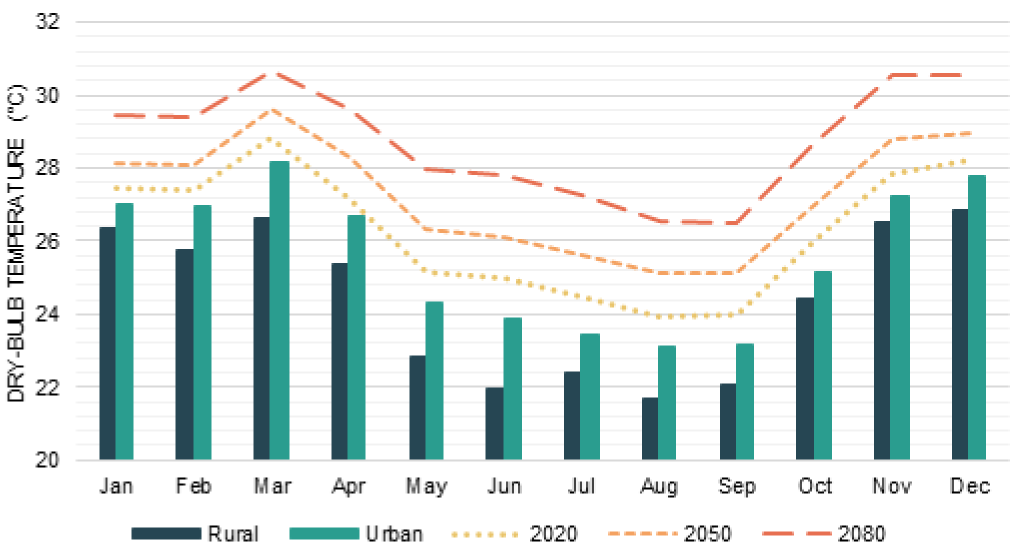
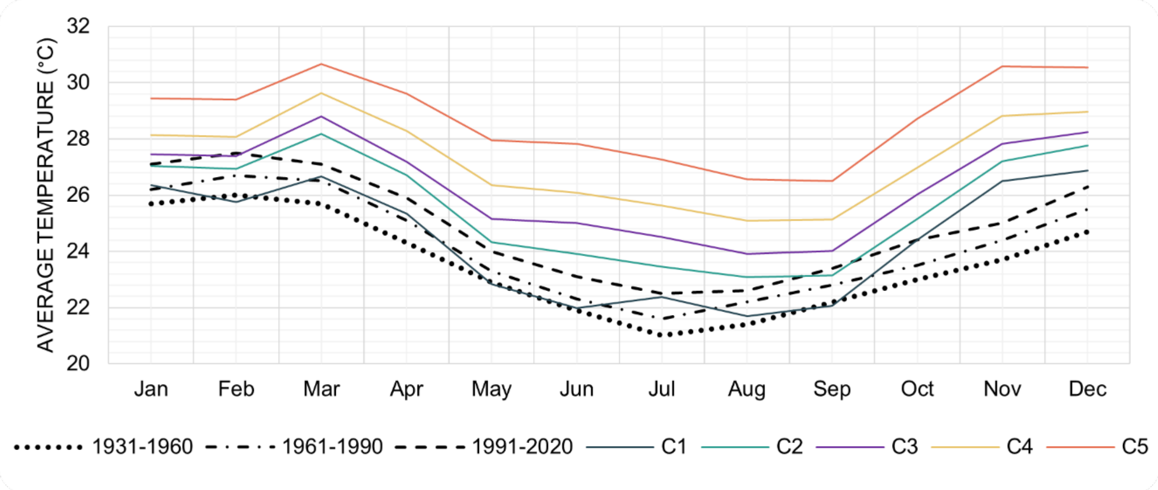


Figure 4 shows the variations in temperature found when switching from the rural weather file to the urban in the year 2018 and, from this change, the projections for the future years. Unlike the data from the original weather file (C1), which pointed out December as the hottest month, March continued to display the highest monthly average in the following scenarios. Likewise, in the years 2020 and 2050, the month of August continued with the lowest monthly average, except 2080, in which the month of September showed lower values, although very close to the value obtained in August.

With the urban file, it was verified that in the month of June there were the highest increases in temperature in the evaluated scenarios, with an increase of 1.10 °C, 1.08 °C and 1.73 °C for the years 2020, 2050 and 2080 respectively. When comparing the original rural file (C1) with the worst thermal scenario (C5), one can see that the month above mentioned reached a total increase of 5.83 °C.

By comparing the results obtained from the simulation with the monitored data of the monthly average temperature of Vitória shown in Figure 1, it is possible to verify that the months with the highest and the lowest averages coincided with the periods of typical summer and winter temperatures, indicated in the historical series of the city (Figure 5). Although June has been the month which showed the highest thermal variation, when the original file was transformed into an urban file, and then adapted to the climate change, concerning the monitored data it showed the lower thermal variation along the reported period.

Figure 5: Profiles of monthly average temperature in monitored periods and in simulated scenarios.



Although the values obtained from the simulated scenarios correspond to the thermal standard which are typical for the local summer and winter, there was not a consistency between the months with higher temperatures verified in the research and in the monitored data. Concerning the latter, February showed the highest monthly averages, whereas in the simulated scenarios, the highest temperatures occurred in March. Likewise, the month of April showed a higher temperature increase in the last decades (1.6 °C), while in the research this increase was verified in the month of June (5.83 °C). Besides that, from the first interval (1931-1960) to the third (1981-2010), it was observed an increase in the monthly average temperature between 0.4 °C and 1.6 °C, which agrees with the warming tendency shown at the report State of the Climate: Global Climate Report for Annual 2019 of NOAA National Centers for Environmental Information.

It is observed that the average month temperature leaned to increase along the decades evaluated, as February and July presented, respectively, the highest and the lowest monthly average temperatures in the three periods. In general, it was observed that the temperature profile changed once the calculation of the effects from the external environment was done, which determined how it would be in the following years, although variations were observed to a greater or lesser degree. The comparative analysis between the simulated and the monitored data indicated that, even though it was verified a tendency of a gradual increase in temperature in the future years, the thermal variations not always remain proportional to the values measured in the previous years.

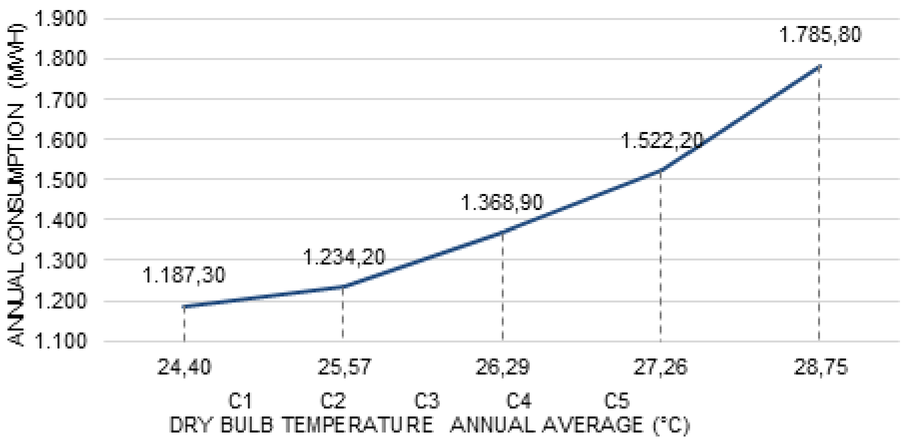
Such oscillations have also been verified for the monthly averages of the scenarios, in which the bigger range occurred in June, May and November, respectively to the evolution of C3, C4 and C5, thus in this first month there was a lower increase in temperature in C4 than in the previous year. In addition, it was observed that the climate change expected in the scenario of emissions HadCM3 A2 contributed significantly for the rise of the external temperature. Therefore, in the face of possible thermal inconsistency, the comparison of profiles and its variations allows the identification of the months when it will be necessary the best adaptation of the building to the higher or lower temperature specified.

3.3 Electric Energy Consumption

The first results in energy consumption appear with configurations exclusively for the main building, which serve as the base value for the comparison with the other scenarios. As to the scenario C1, the building showed an annual energy consumption of 1,187.30 MWh. However, after the insertion of the urban surrounding (C2), there was an increase of 3.80% (46.90 MWh), resulting in 1,234.20 MWh. Such data corroborate the importance of the UBEM, which considers the influence of the surroundings on the energy simulations, according to Reinhart and Cerezo (2016) and Natanian, Aleksandrowicz and Auer (2019).

It is necessary to insert external influences on simulations in order to have a more precise energy evaluation mainly because the increase of dry-bulb temperature in future projections (detailed in item 3.2), generates a higher energy consumption every year, as demonstrated in Figure 6. In scenario C3, the energy consumption reached a total of 1,368.90 MWh, which represents an increase of 9.84% (134.70 MWh) compared to C2. On the other hand, in other scenarios, 2050 and 2080, the total increase was progressive, in 10.07% (153.30 MWh) and 14.76% (263.60 MWh) which resulted in 1,552.20 MWh and 1,785.80 MWh, respectively, of total consumption.

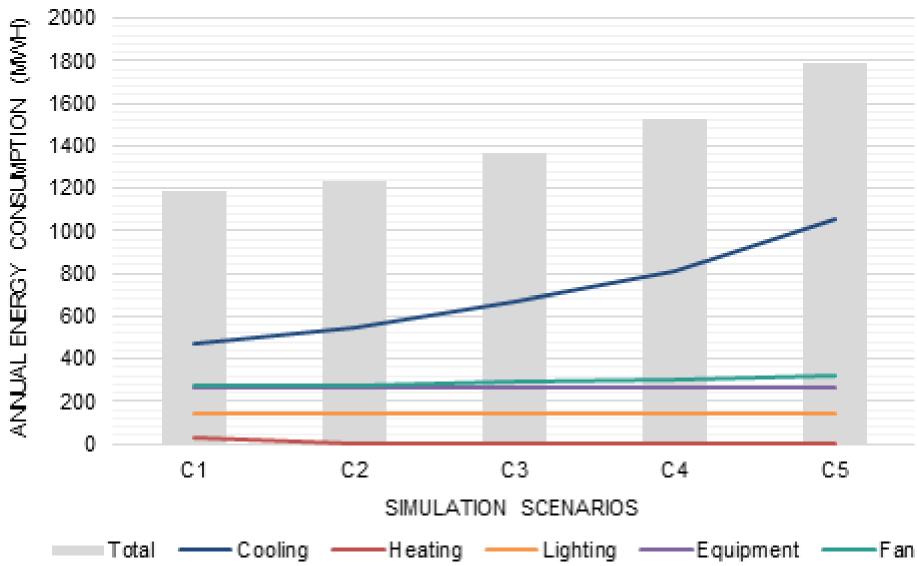
Figure 6: The relation between the energy consumption and the dry-bulb temperature.



As observed in Figure 6, the total energy consumption tends to increase in the hottest months. Since the first scenario (C1), it was verified a significant influence of the cooling system on energy consumption, which corresponded alone to 39.84% (473.06 MWh) of the energy consumed, while the rest of the elements responsible for energy consumption refers to 2.73% of heating (32.48 MWh) and 12.08% of lighting (143.45 MWh) systems and to the equipment and mechanical ventilation.

Along the simulation, the energy consumption from the cooling system increased in 10.07% (64.11 MWh) with the insertion of the urban surroundings (C2) and 18.35% (122.39 MWh), 17.63% (142.69 MWh) and 23.35% (246.63 MWh) in the future scenarios of 2020, 2050 and 2080, respectively. There was also an increase of up to 15% in the energy consumption referring to the mechanical ventilation in scenario C5, in which the energy consumption of the lighting and equipment remained constant, since the alteration of consumption of these systems are not influenced directly by climate change (Figure 7). With the sequential substitution of the scenarios, it was observed a discrepancy in the energy consumption of the heating and cooling activities, where there was a reduction of 99.87% for the first and an increase of 55.21% for the second.

Figure 7: The proportion of different systems in final consumption.



In Figure 7, it is possible to observe the substantial increase on the energy consumption related to the cooling system in comparison with the other systems. In 2080, the energy consumption of the cooling system on the building totaled 59.14%, which was equivalent to 1,056.10 MWh, confirming the priority of measures to reduce the effect of climate changes on the expenditure with this specific system.

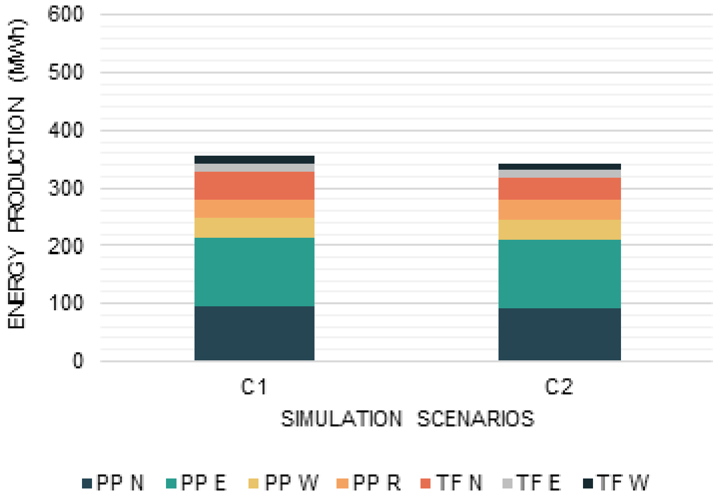
3.4 Solar Energy Generation

Composed by photovoltaic panels positioned on the North, East and West facades, besides the roof of the building, the configuration of the energy production system consisted in the compliance of the building with the Zero Energy concept, by capturing the radiation incident on the building, with values varying from 522.50 to 1,049.20 kWh/m^2.

On that matter, the photovoltaic energy generation system installed for scenario C1 produced 355.87 MWh/year, corresponding to 29.97% of the total consumption of energy of the evaluated building. It should be noted that the share of each photovoltaic technology in the final amount of energy generated was 78.94% (280.92 MWh/year) for the monocrystalline silicon panels and 21.06% (74.94 MWh/year) for the thin film of cadmium telluride. Concerning scenario C2, the production of the system mentioned reached 342.18 MWh/year, 27.72% of the total consumption of energy. These production numbers were: 81.22% (277.92 MWh/year) from the photovoltaic panels and 18.78% (64.26 MWh/year) from the photovoltaic thin-films.

It was observed that, after the insertion of the specifications for materiality and obstructions of the urban context, there was a reduction of 3.85% (13.69 MWh/year) compared to the previous scenario (Figure 8). Thus, it was verified that the productivity of the panels and of the photovoltaic films may be affected by external parameters, such as high temperature and inadequate radiation incidence, which proves the influence of the surroundings, according to the results of the studies done by Boccalatte, Fossa and Menezo (2020).

Figure 8: Energy generation for scenarios C1 and C2.

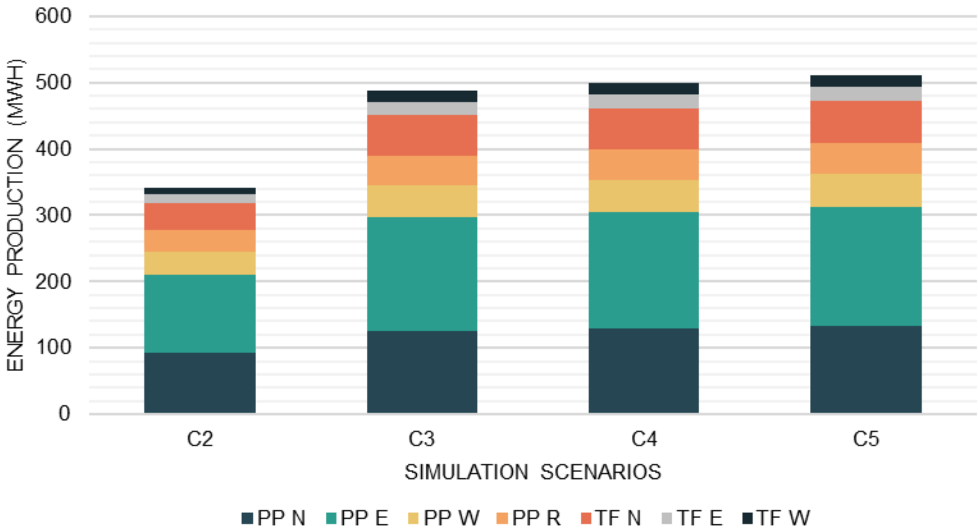


In light of this, another issue to be considered is the variation of the radiation on different facades and floors of the building, which establish different levels of productive capacity of the envelope. In Figure 8, it is possible to observe the energy production of each component of the system, represented by "PP" and "TF", which correspond respectively to photovoltaic panels and thin-films, followed by their orientation – West (W), East (E) or North (N) – or the installation on the roof (R).

In all scenarios, the panels installed on the North facade showed better results in production and the lowest values correspond to the thin-films on the West facade. Thus, it is possible to infer that despite the expected production for each panel and film, the linearity published by the manufacturers of panels is affected by external factors, which determine the real efficiency of the photovoltaic solar energy generation system.

Unlike scenario C1, the Figure 9 shows future scenarios with the insertion of data from the urban context, in which it is possible to observe a significant increase of 2.33% (11.66 MWh/year) and 2.32% (11.87 MWh/year), respectively to the time interval of C3 to C4 and between C4 and C5. Since a great variation was not noted, the data are in accordance with the study of Cocco and Costa (2019), in which it was verified a reduction of the average efficiency of the photovoltaic energy system along the future years due to the gradual decline in the use of solar energy when comparing to C1 and C2 increase efficiencies.

Figure 9: Energy generation in scenarios C2, C3, C4 and C5.



According to the resulting performance of the energy production system in each evaluated scenario, it was possible to determine that the amount of total energy reached between 27.72% to 35.61% of the total final energy consumption of the proposed building. This energy produced, with the optimization measures of the building, represents the intent to reduce energy consumption and it is in accordance with the characteristics mentioned by Kurnitzki *et al*. (2011) to define a Nearly Zero Energy building.

However, the amount of energy generated by the system was not enough to meet the total demand of the building, and least of all to provide for a good part off consumption determined by the Directive 2010/31/EU (Kurnitzki *et al*., 2011; Boccalatte *et al*., 2020). Even with the result of a little more than 1/3 of the total annual consumption, the evaluation of the applicability of the nZEB concept for buildings in the section is positive, mainly when the environmental conditions are favorable to its implementation.

4 Conclusion

The changes in climate in urban areas of the tropical zone potentially cause impacts on the energy behavior of buildings. Given this scenario, and aiming to identify the real effect of climate change on the energy performance of nZEB buildings projected for a characteristically tropical urban environment, this study adopted a building model to make a comparative analysis of several possible scenarios.

Concerning the methodology used, it is worth mentioning that the UWG tool allowed the verification of the urban heat island effect after the addition of the considered constructive geometry. Besides the increase in temperature in the urban areas, this effect resulted in the reduction of the capacity of production of the photovoltaic panels due to the excess heat and, together with the obstruction of the radiation by the surrounding buildings, it affected the level of efficiency of energy generation.

As seen in the results of the evaluations, the production of photovoltaic energy was not enough to meet the energy demand of the building. It is assumed that, in the face of space conditioning growth, particularly in commercial buildings, the energy demand in buildings and the photovoltaic energy not only should work with to equate yearly production to consumption, but also it should be considered that energy production has to be increased by nearly 70% until 2080 to fill the consumption gap and reduce it to zero. Furthermore, these analyses work together to develop more assertive propositions and enhance nZEB buildings, as the primary strategies to mitigate consumption could turn out not as effective as they should be.

The limitations found in this study are related to the meteorological data made available at the weather file of the city which, due to the fact that the existing time interval is smaller than recommended by Jentsch *et al*. (2013), lead to an inconsistent estimate of the dry-bulb temperature and of the values of radiation when changed to future scenarios. However, it should be noted that, despite the limiting data, the proportions found among the scenarios are in accordance with the expected for the future years, as indicated at the IPCC report. The amount of energy reached was affected by adverse environmental conditions imposed on the model, as for example, the solar obstructions caused by the surrounding high residential and commercial buildings.

Despite the unfavorable results to the energy balance and the limitations found with the verified local meteorological data during the simulation process applied, it is clearly seen that there are future possibilities to even consumption with energy production either through on-site production of energy and favorable urban conditions, or through the cogeneration of energy in solar plants.

Acknowledgements

The authors gratefully acknowledge the financial support received from the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) and the Fundação de Amparo à Pesquisa e Inovação do Espírito Santo (FAPES).

References

AGÊNCIA DE SERVIÇOS PÚBLICOS DE ENERGIA DO ESTADO DO ESPÍRITO SANTO. **Energia solar no Espírito Santo - Tecnologias, aplicações e oportunidades**. Vitória, ES, 2013.

ALVI, Shahzad; MAHMOOD, Zafar; NAWAZ, Shahzada. Dilemma of direct rebound effect and climate change on residential electricity consumption in Pakistan. **Energy Reports**, v. 4, p. 323-327, 2018. Available on: https://doi.org/10.1016/j.egyr.2018.04.002. Accessed: 16 May 2020.

AMERICAN SOCIETY OF HEATING REFRIGERATING AND AIR-CONDITIONING ENGINEERS – ASHRAE. **ANSI/ASHRAE Standard 55-2017:** Thermal Environmental Conditions for Human Occupancy. United States of America: [s.n.]. 2017a.

AMERICAN SOCIETY OF HEATING REFRIGERATING AND AIR-CONDITIONING ENGINEERS - ASHRAE. **ASHRAE Handbook - Fundamentals**. 2017. ed. Georgia, United States of America: ASHRAE, 2017b.

ATHIENITIS, Andreas; O'BRIEN, William. **Net ZEB case studies. Modeling, Design, and Optimization of Net-Zero Energy Buildings**, p. 241-350, 2015. ISBN: 9783433604625.

BOCALLATTE A.; FOSSA, M.; MÉNÉZO, C. Best arrangement of BIPV surfaces for future NZEB districts while considering urban heat island effects and the reduction of reflected radiation from solar facades. **Renewable Energy**, v. 160, p. 686-697. 2020. Available on: https://doi.org/10.1016/j.renene.2020.07.057. Accessed: 28 Aug 2020.

BUENO, Bruno; NORFORD Leslie; HIDALGO Julia; PIGEON Grégoire. The urban weather generator. **Journal of Building Performance Simulation**, v. 6, p. 269-281. 2013. Available on: https://doi.org/10.1080/19401493.2012.718797. Accessed: 13 Nov 2020.

CAO, Xiaodong; DAI, Xilei; LIU, Junjie. Building energy-consumption status worldwide and the state-of-the-art technologies for zero-energy buildings during the past decade. **Energy and buildings**, v. 128, p. 198-213, 2016. Available on: https://doi.org/10.1016/j.enbuild.2016.06.089. Accessed: 6 May 2020.

CIDADE-BRASIL. Estado do Espírito Santo. Município de Vitória. 2020. Available on: https://www.cidade-brasil.com.br/municipio-vitoria.html. Accessed: 30 Dec 2020.

CONSELHO BRASILEIRO DE CONSTRUÇÕES SUSTENTÁVEIS - CBCS. **Desempenho Energético Operacional em Edificações**: Relatório Final-Benchmarking de escritórios corporativos e recomendações para certificação DEO no Brasil. São Paulo: CBCS, 2015.

COCCO, Daniel; COSTA Alexandre. M. S. Effect of a global warming model on the energetic performance of a typical solar photovoltaic system. **Case Studies in Thermal Engineering**, v. 14, p. 100450. 2019. Available on: https://doi.org/10.1016/j.csite.2019.100450. Accessed: 20 Oct 2020.

CORREA, Wesley de Souza Campos. **Campo térmico e higrométrico da Regional Praia do Canto no município de Vitória (ES)**. 2014. Dissertação (Mestrado em Geografia) – Universidade Federal do Espírito Santo, Vitória, 2014.

DAVILA, Carlos Cerezo; REINHART, Christoph; BEMIS, Jamie. Modeling Boston: A workflow for the generation of complete urban building energy demand models from existing urban geospatial datasets. **Energy**, v. 117, p. 237-250, 2016. Available on: https://doi.org/10.1016/j.energy.2016.10.057. Accessed: 21 Jun 2020.

EMPRESA DE PESQUISA ENERGÉTICA - EPE. **Mudanças Climáticas e desdobramentos sobre os estudos de planejamento energético: considerações iniciais**. 2018. Available on: http://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-227/topico-457/Mudancas%20Climaticas%20e%20Planejamento%20Energetico.pdf. Accessed: 25 May 2020.

EMPRESA BRASILEIRA DE PESQUISA AGROPECUÁRIA. **Clima**. [*s.d.*]. Available on: https://www.cnpf.embrapa.br/pesquisa/efb/clima.htm. Accessed: 13 Nov 2020.

FERRARA, Maria; FABRIZIO, Enrico. Cost optimal nZEBs in future climate scenarios. **Energy Procedia**, v. 122, p. 877-882, 2017. Available on: https://doi.org/10.1016/j.egypro.2017.07.377. Accessed: 02 Jun 2020.

FRAGA, Anderson Azevedo. **Potencial de adoção do conceito Zero Energy para edificações comerciais em Vitória/ES**. 2020. Dissertação (Mestrado) – Curso de

Arquitetura e Urbanismo, Universidade Federal do Espírito Santo, Vitória, 2020. Disponível em: https://sappg.ufes.br/tese_drupal//tese_14274_ANDERSON%20AZEVEDO%20FRAGA%20-%20VERS%C3O%20FINAL.pdf. Acesso em: 27 mar. 2023.

GRASSHOPPER3D. Grasshopper. 2021. Available on: https://www.grasshopper3d.com/.

GUARDA, Emeli; DOMINGOS, Renata; JORGE, Stefany; DURANTE, Luciane; SANCHES, João Carlos; LEÃO, Marlon; CALLEJAS, Ivan Julio. The influence of climate change on renewable energy systems designed to achieve zero energy buildings in the present: A case study in the Brazilian Savannah. **Sustainable Cities and Society**. v. 52, p. 101843. 2020. Available on: https://doi.org/10.1016/j.scs.2019.101843. Accessed: 02 Sep 2020.

JENTSCH, Mark; JAMES, Patrick; BOURIKAS, Leonidas; BAHAJ, AbuBakr. Transforming existing weather data for worldwide locations to enable energy and building performance simulation under future climates. **Renewable Energy**, v. 55, p. 514-524. 2013. Available on: https://doi.org/10.1016/j.renene.2012.12.049. Accessed: 15 May 2020.

INSTITUTO NACIONAL DE METEOROLOGIA (INMET). **Clima**. NorMays climatológicas. Gráficos. Available on: https://clima.inmet.gov.br/GraficosClimatologicos/DF/83377. Accessed: 13 Nov 2020.

INTERNATIONAL ENERGY AGENCY (IEA). **World Energy Outlook 2021**. 2021. Available on: https://iea.blob.core.windows.net/assets/4ed140c1-c3f3-4fd9-acae-789a4e14a23c/WorldEnergyOutlook2021.pdf. Accessed: 20 Apr 2022.

INTERNATIONAL ENERGY AGENCY (IEA). **Electricity Market Report - January 2022**. 2022. Available on: https://www.iea.org/reports/electricity-market-report-january-2022. Accessed: 24 Apr 2022.

INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (IPCC). **Climate Change 2014**: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, p. 151. 2014. ISBN: 978-92-9169-143-2.

INSTITUTO JONES DOS SANTOS NEVES. **Espírito Santo em mapas**. 3 ed. Vitória, 2011. Available on: http://www.ijsn.es.gov.br/ConteudoDigital/20120823_es_em_mapas_3_edicao.pdf. Accessed: 13 Nov 2020.

HONG, Tianzhen; CHEN, Yixing; LUO, Xuan; LUO, N.; LEE, Sang Hoon. Ten questions on urban building energy modeling. **Building and Environment**, v. 168. 2020. Available on: https://doi.org/10.1016/j.buildenv.2019.106508. Accessed: 26 May 2020.

KURNITSKI, Jarek; ALLARD, Francis; BRAHAM, Derrick; GOEDERS, Guillaume; HEISELBERG, Per; JAGEMAR, Lennart; KOSONEN, Risto; LEBRUN, Jean; MAZZARELLA, Livio; RAILIO, Jorma; SEPPÄNEN, Olli; SCHMIDT, Michael; VIRTA, Maija. How to define nearly net zero energy buildings nZEB. **Rehva Journal**, v. 48, n. 3, p. 6-12, 2011. Available on: https://www.rehva.eu/fileadmin/hvac-dictio/03-

2011/How_to_define_nearly_net_zero_energy_buildings_nZEB.pdf. Accessed: 5 May 2020.

LIMA, Izabella; SCALCO, Veridiana; LAMBERTS, Roberto. Estimating the impact of urban densification on high-rise office building cooling loads in a hot and humid climate. **Energy and Buildings**, v. 182, p. 30-44. 2019. Available on: https://doi.org/10.1016/j.enbuild.2018.10.019. Accessed: 26 May 2020.

MAUREE, Dasaraden; NABONI, Emanuele; COCCOLO, Silvia; PERERA, Amarasinghage; NIK, Vahid; SCARTEZZINI, Jean-Louis. A review of assessment methods for the urban environmental and its energy sustainability to guarantee climate adaptation of future cities. **Renewable and Sustainable Energy Reviews**, v. 112, p. 733-746. 2019. Available on: https://doi.org/10.1016/j.rser.2019.06.005. Accessed: 11 May 2020.

MCNEEL & ASSOCIATES. Rhinoceros. Available on: https://www.rhino3d.com/. Accessed: 7 May. 2021.

MOLDOVAN, M.; VISA, I.; DUTA, A. Future trends for solar energy use in nearly zero energy buildings. **Advances in Solar Heating and Cooling**, p. 547-569. 2016. Available on: https://www.sciencedirect.com/science/article/pii/B9780081003015000205. Accessed: 25 Apr 2022.

NAKANO, Aiko; BUENO, Bruno; NORFORD, Leslie; REINHART, Christoph. Urban Weather Generator: a novel workflow for integrating urban heat island effect within urban design process. **14th Conference of International Building Performance Simulation Association**, BS2015, 7-9 December, 2015, Hyderabad, India, IBPSA, 2015. Available on: https://dspace.mit.edu/handle/1721.1/108779. Accessed: 11 May 2020.

NATANIAN, Jonathan; ALEKSANDROWICZ, Or; AUER, Thomas. A parametric approach to optimizing urban form, energy balance and environmental quality: The case of Mediterranean districts. **Applied Energy**, v. 254, p. 113637. 2019. Available on: https://doi.org/10.1016/j.apenergy.2019.113637. Accessed: 05 May 2020.

NATANIAN, Jonathan; AUER, Thomas. Beyond nearly zero energy urban design: A holistic microclimatic energy and environmental quality evaluation workflow. **Sustainable Cities and Society**, v. 56, p. 102094. 2020. Available on: https://doi.org/10.1016/j.scs.2020.102094. Accessed: Accessed: 15 May 2020.

REINHART, Christoph; DAVILA, Carlos Cerezo. Urban building energy modeling - A review of a nascent field. **Building and Environment,** v. 97, p. 196-202. 2016. Available on: https://doi.org/10.1016/j.buildenv.2015.12.001. Accessed: 31 Aug 2020.

SHEN, Pengyuan; LIOR, Noam. Vulnerability to climate change impacts of present renewable energy systems designed for achieving net-zero energy buildings. **Energy**, v. 14, p. 1288-1305. 2016. Available on: https://doi.org/10.1016/j.energy.2016.07.078. Accessed: 03 Oct 2020.

WORLD METEOROLOGICAL ORGANIZATION (WMO). **State of Global Climate 2021 - WMO Provisional report**. 2021. Available on: https://library.wmo.int/doc_num.php?explnum_id=10859. Accessed: 20 Apr 2022.