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Comparison Study and Assessment of Thermal Performance and Energy Self-sufficiency of Nearly Zero Energy Building (nZEB) in Two Different Climates

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Abstract. The paper presents a comparative study of a nearly zero-energy office building with respect to two different cities located in two different climate zones: a humid continental climate with dry winter, represented by the city of Seoul and a hot semi-arid climate, represented by the city of Benguerir. Obviously, climate is one of the most influential factors affecting indoor thermal comfort, energy demand and energy self-sufficiency of nZEBs. In this study, we first assess the impact of regional climate on the thermal performance, and we explore the influence of the local natural energy sources on the Solar BIPV and PV outputs in the two different cities: Benguerir and Seoul, respectively. And then, we explore the overall energy self-sufficiency of the nZEB for the respective climates. The differences in thermal need and energy self-sufficiency responses were statistically significant. With respect to Benguerir, the thermal energy needs for cooling amount to 71.5 kWh/m²/year, with almost no heating thermal needs and the Energy Balance (EB) reaches 0.88. On the other side, these metrics are around 52.56 kWh/m²/year for the total thermal needs with a share of 43% for heating thermal needs and a yearly EB equals to 0.6 for the nZEB in Seoul. Finally, it is important to mention that the BIPV output share out of the total solar energy output amounts to 57% and 61% for the cities of Seoul and Benguerir, respectively, which highlight the important role of BIPV in reaching advanced levels of energy self-sufficiency.

Keywords: Nearly Zero Energy Building; Energy Efficiency; BIPV; Photovoltaic; Net zero energy building; Self-Sufficiency.

1 Introduction

Designing net zero energy buildings is becoming increasingly important due to the urgent need to reduce greenhouse gas emissions and mitigate the effects of climate change [1].

Net zero energy buildings are designed to produce as much energy as they consume, resulting in a net zero energy balance [2]. This is achieved through a combination of energy-efficient design, the use of renewable energy sources, and advanced building technologies [3].

By designing net zero energy buildings, we can significantly reduce our reliance on fossil fuels and decrease greenhouse gas emissions. This not only helps to mitigate the negative effects of climate change, but it also helps to reduce energy costs and create more sustainable and resilient communities [4].

Furthermore, designing net zero energy buildings can also have a positive impact on human health and well-being. These buildings are designed to provide high-quality indoor air, natural light, and comfortable temperatures, which can improve occupant health and productivity [5]. As such, the main objective of this

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paper is to contribute to the promotion of the new role of Nearly Zero Energy Buildings (nZEBs) as a prosumer by the interplay between on-site generation and the building loads, often assessed by Energy Balance.

In summary, designing nZEBs is crucial for mitigating climate change, reducing energy costs, and improving human health and well-being. As such, it should be a priority for the building industry and policymakers around the world.

In addition to the above, reaching net zero energy building does depend, in part, on the availability of regional natural energy resources. Thus, assessing local climate conditions is crucial in the design of nZEBs. By understanding the local climate, designers can develop contextual strategies to optimize energy performance and reduce the energy demand of the building [6].

Some key climate factors that impact building design include temperature ranges, solar radiation, humidity levels, and wind patterns. For example, a building located in a hot and humid climate may require additional strategies to reduce cooling loads, such as shading devices or natural ventilation. In contrast, a building located in a colder climate may require additional insulation and efficient heating systems to minimize heat loss.

Moreover, assessing the local climate can also help inform designers about the building's orientation and layout. For instance, a building designed to take advantage of passive solar heating strategies will need to be oriented to maximize south-facing windows, while also avoiding excessive solar gain in warmer months.

Finally, understanding the local climate can help determine the most effective renewable energy technologies to incorporate into the building design. For example, a building located in a region with abundant solar radiation may benefit from the installation of solar panels, while a building located in a region with strong and consistent winds may benefit from the installation of a wind turbine.

2 Assessment of Local Climate Conditions - Analysis Per Location

Assessing local climate conditions is critical in designing net zero energy buildings as it provides crucial information to guide decisions on building design and technology selection. By understanding the local climate, designers can optimize the building's energy performance and increase its ability to achieve net zero energy status.

In more detail, the seasonal course of temperatures and humidity can be observed in the maximum and minimum temperature and relative humidity plots (Figure 2), in two extreme months of the year.

Besides temperature and relative humidity, relevant meteorological variables for the current study are wind speed and direction, which can be visualized with the wind roses as displayed in Figure 1.

2.1 Climate characteristics of Seoul

Seoul, the capital city of South Korea, has a temperate climate with four distinct seasons. The summers are hot and humid, while the winters are cold and dry. The annual average temperature is around 12.8°C, with the highest temperatures occurring in July and August, when the average daily temperature is around 26.2°C. The lowest temperatures occur in January and February, when the average daily temperature is around -2.3°C (Figure 2).

Seoul receives a moderate amount of precipitation throughout the year, with the rainy season typically occurring from June to September. The annual precipitation average is around 1,300mm.
Seoul has a humid continental climate with less sunshine. On average, Seoul receives about 1189 kWh/m²/year as Global Horizontal Radiation (GHI) (Figure. 3).

Overall, the climate characteristics of Seoul require careful consideration in the design of net zero energy buildings, with a focus on efficient heating and cooling strategies and the use of clean and renewable energy sources.

2.2 Climate characteristics of Benguerir

Benguerir is a city located in central Morocco, with a desert climate characterized by hot summers and cool winters. The city experiences very low precipitation and is considered one of the driest regions in Morocco [7].

During the summer months of June to September, temperatures in Benguerir can reach up to 44°C, with very low humidity levels and with daily temperatures averaging around 29.1°C in the month of August. During the winter months of December to February, temperatures can drop down to 1.7°C at night, with daily temperatures averaging around 12°C in January (Figure 2).

Benguerir receives very little precipitation, with an average annual rainfall of only 160mm per year. The majority of the rain falls during the winter months, and the city may also experience occasional flash floods during this time.

Benguerir has a hot desert climate with abundant sunshine. This makes it an excellent location for solar energy production. On average, Benguerir receives about 1983 kWh/m²/year as Global Horizontal irradiation (GHI) (Figure 3).

Given the hot and dry climate, building design in Benguerir should prioritize cooling strategies. Passive cooling strategies, such as natural ventilation, shading

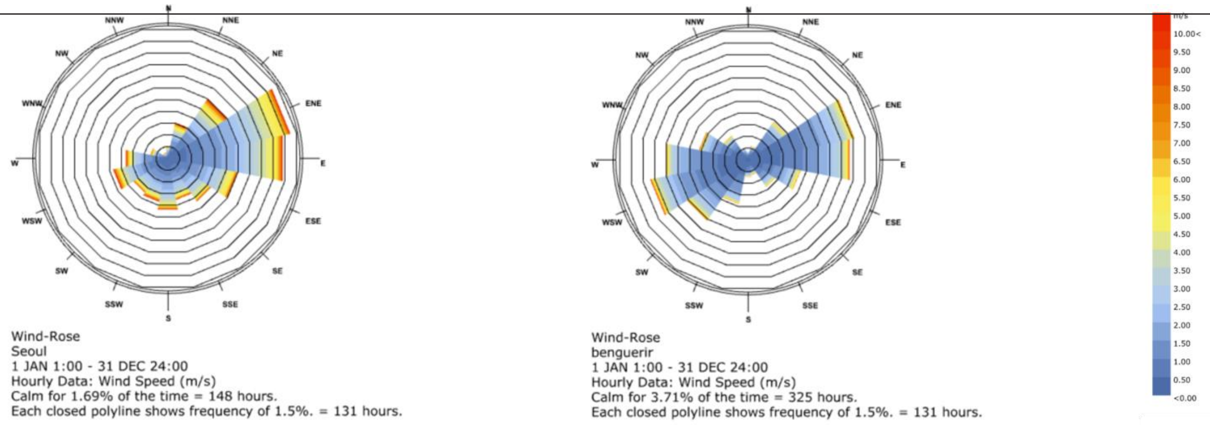

Figure 1: Wind-rose for the two locations: Seoul and Benguerir

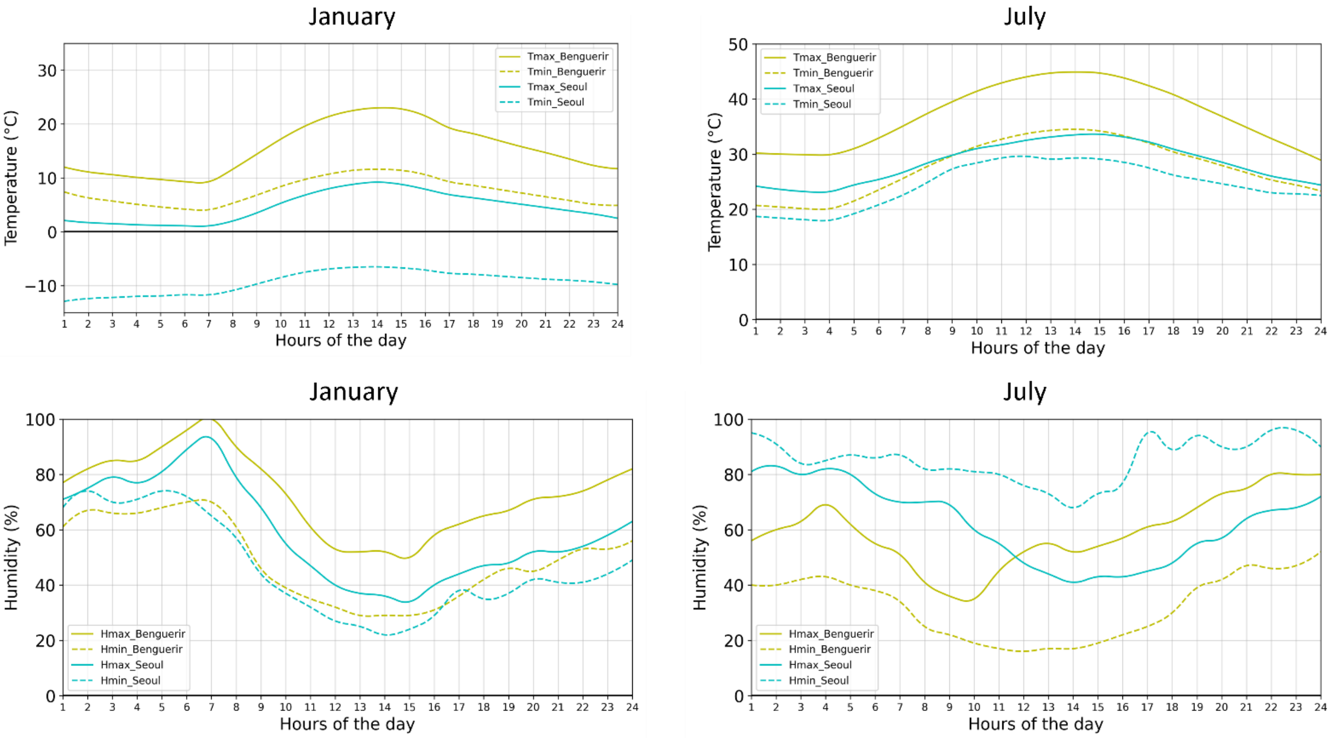

Figure 2: Maximum and Minimum Temperature and Relative humidity profiles for months of January and July for the two locations

devices, and the use of cool roofs, can help reduce cooling loads and energy consumption. The use of thermal insulation and efficient windows can also help maintain a comfortable indoor temperature.

Overall, the hot and dry climate of Benguerir requires careful consideration in building design to ensure energy efficiency and thermal comfort, with a focus on passive cooling strategies and the use of renewable energy technologies such as solar energy.

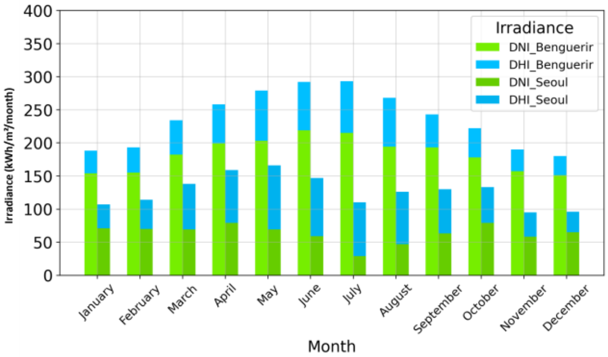

Figure 3: Monthly irradiance (DNI & DHI) for Benguerir and Seoul

3 METHODOLOGY AND TOOLS

3.1 Case study

This paper uses a digital parametric workflow through grasshopper. Environmental and energy-based assessments were carried out considering a detached 30-meter-by-30-meter five-storey solar-powered glazed office building with internal characteristics for occupancy, lighting, and equipements' schedules described in Table 1. Each storey is composed of 3-meter occupied area and a 1-meter unconditioned plenum.

While evaluating the thermal energy demand at early urban design phases, a 'core and shell' thermal zoning strategy was implemented, based on the strategy offered in ASHREA 90.1 [8] and Following the thermal zoning method described by Reinhart et al [9]. Each floor is divided between internal and four perimeter zones.

Focusing on exploring the potential of solar energy in the urban landscape, we propose a model to assess the spatiotemporal variation more fully in the solar potential of buildings: from both the roof-tops and facades.

A BIPV system covers the 2.5-meter width of each story of the facade of a building and integrated into the shading devices. The distance between each BIPV installation and the glazing wall is 0.5 m. The roof PV system covers 50% of the roof's area.

3.2 Energy performance indicators

For each climatic condition, the energy performance metrics – monthly/yearly thermal energy demand and Net Energy Balance performances - were calculated using EnergyPlus [10] and ladybug [11].

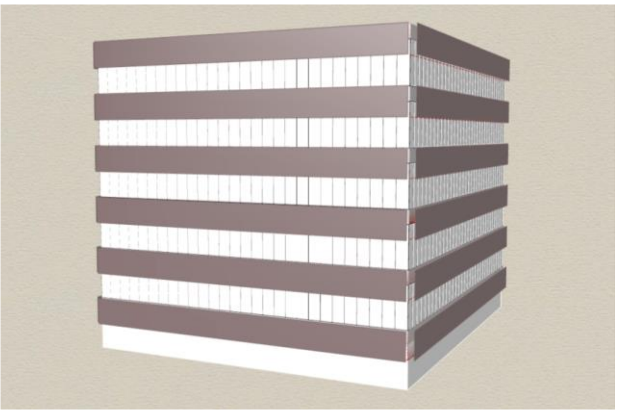

Figure 4: 3D rendering of the Office building

Table 1: Main physical characteristics of the building energy model

Parameters	Composants	Value (Mid-rise Office Building)
Heating/Cooling setpoints		20 °C – 26 °C
COP		3 (Heating and Cooling)
Schedules		Weekdays 08:00-18:00
Zone loads	Lighting	10 W/m²
	Occupancy	0.12 People/m²
	Equipment	8 W/m²
Material prop.:		
	Floors	U = 0.66 W/m²K
	G. Floors	U = 1.2 W/m²K
	Windows	U = 2 W/m²K, SHGC = 0.45, ST=0.35
	Wall	U=0.4 W/m²K
Ventilation		0.7 ACH
BIPV efficiency		16%
PV efficiency		19%

4 RESULTS AND DISCUSSION

The regional and seasonal distribution characteristics of outdoor climate conditions, of the corresponding thermal energy demand, Energy Use Intensities, solar output and finally of the energy self-sufficiencies of the nZEB have been compared and deviation features have been assessed, establishing a clear understanding about the large regional discrepancy in thermal performance and solar energy production from BIPV and PV systems.

4.1 Thermal energy demand

The office building in Benguerir would require more cooling capacity during the summer months, while the same building in Seoul would require more heating capacity during the winter months, as depicted in Figure 5. Besides, the thermal energy needs are 71.47 kWh/m²/year and 52.55 kWh/m²/year for Benguerir and Seoul, respectively.

In Benguerir, buildings would need to be designed to maximize natural ventilation and shading, and to minimize solar gain during the summer months [12][13].

Research studies should further evaluate adapted energy efficiency measures such as external walls' insulation and high thermal mass [14], improved glazing types on the windows [15], airtightness, earth-to-air heat exchanger [16], and all other approaches and systems that serve to increase the efficiency of the building

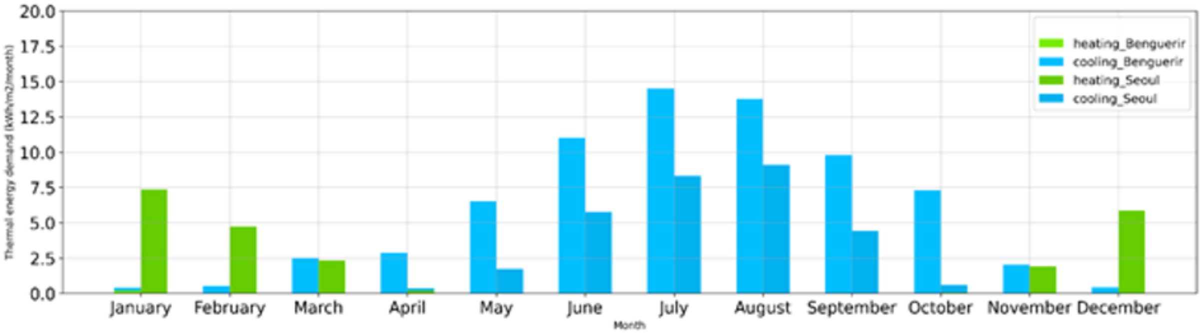

Figure 5: Monthly thermal energy demand for cooling and heating in both cities of Benguerir and Seoul

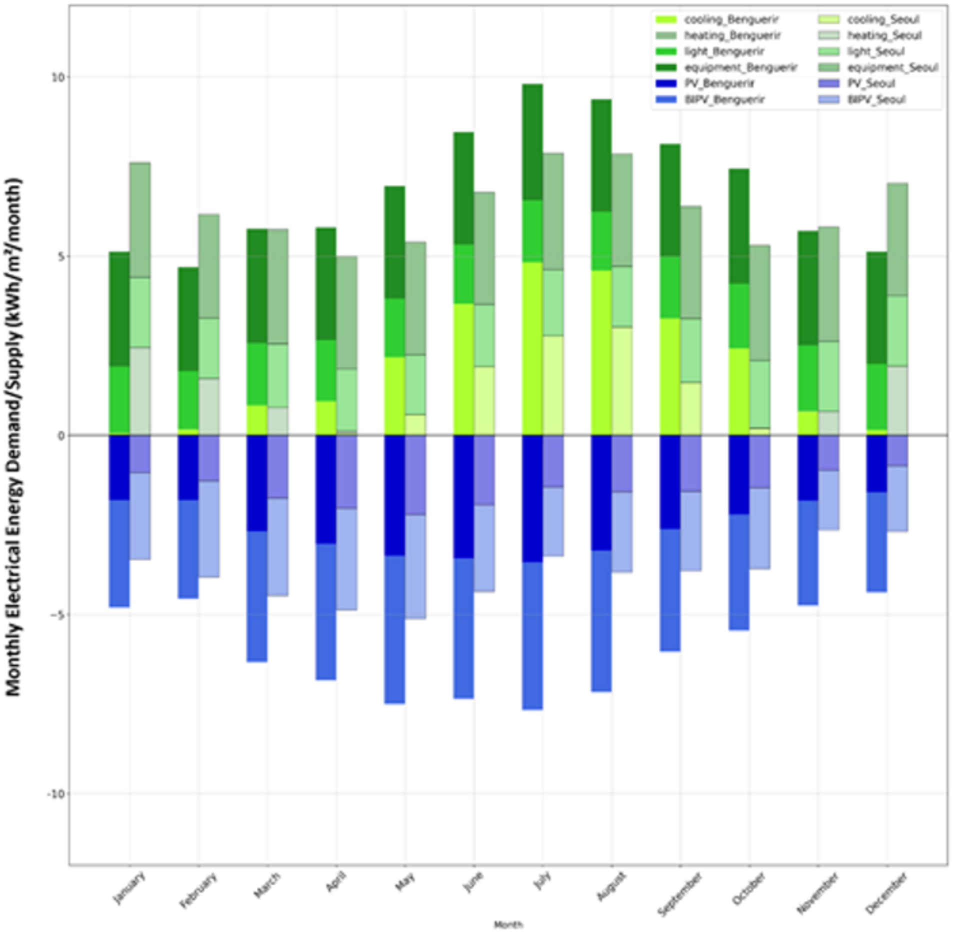

Figure 6*:* Monthly Electrical Energy Demand/Supply in both cities of Benguerir and Seoul

operation and mitigate the increasing energy demand for indoor comfort [17].

Overall, the thermal needs for buildings in Benguerir and Seoul are significantly different due to their contrasting climates, and would require different strategies and technologies to achieve comfortable indoor environments.

4.2 Solar PV and BIPV production

The energy crisis and climate change should prompt stakeholders and designers to accelerate the energy transition by making renewable energy more prominent.

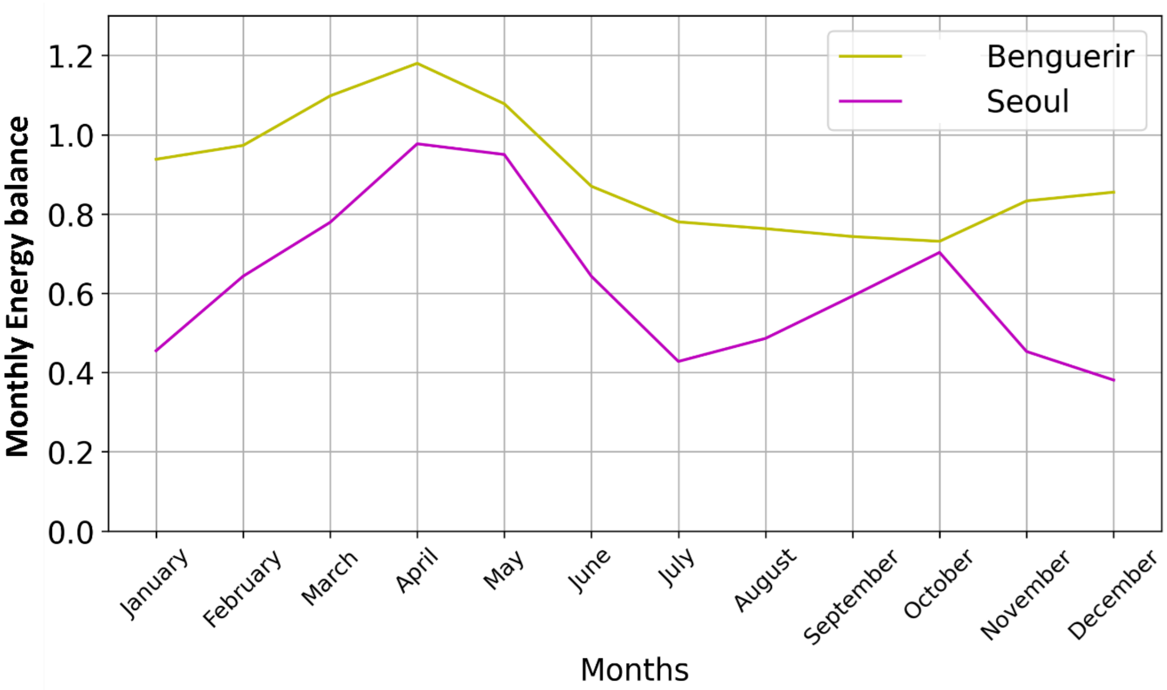

Figure 7: Monthly Net Energy for both cities of Benguerir and Seoul

The differences in solar irradiance between Benguerir and Seoul, as presented in Figure 3, affects the energy production of solar panels in these locations. PV and BIPV panels in Benguerir would generate 72.85 kWh/m² and therefore more by 57.35% that what can be produced by these solar panels in Seoul. Hence, in terms of renewable energy resources, Seoul has limited potential for solar power compared to Benguerir.

BIPV solar output covers 57.3 % and 60.8% of the total solar output in Benguerir and Seoul, respectively. This being so, BIPV systems play an important role in improving the self-sufficiency of buildings and cover a large share of the total in-situ solar output.

Renewable energy technologies, particularly solar energy, could be a viable option for Benguerir, given its high solar radiation levels. This high potential of solar energy could support the ambitions of decarbonation on an urban scale.

The findings reveal substantial seasonal differences in which the monthly EB could fluctuate between 73% and 118% in Benguerir, whereas it fluctuates between 38% and 98% in Seoul. Additionally, the yearly EB is 88.4% in Benguerir against 60.14% in Seoul.

Furthermore, Figure 7 depicts the seasonal EB, which can act as an indicator for both district-level energy management and utility grid demand management.

5 CONCLUSION

Based on the findings of this study, it is therefore quintessential to consider the regional climate-responsive design adaptations by understanding local climate and the changing seasons, in order to meeting dual targets of indoor thermal environment improvement and reaching energy Self-sufficiency of nZEB. Besides, the PV system installation, BIPV systems have major impact out of the total installed solar energy system on improving the self-sufficiency of nZEB, as the BIPV's solar output covers up to 60.8% of the total solar energy production of a building.

Strategically, these results demonstrate the importance of the parametric workflow to help designers to assess the impact of the climate responsive design strategies on the energy and environmental performance considerations. Besides, our methodology sheds the light on the role of parametric design to link between the parametric buildings and their local climatic conditions. Its application should help designers and policy makers to contextualize and adapt nearly zero energy building concepts considering the urban context and the climatic conditions.

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