Research on the establishment of Net-Zero Energy Buildings (NZEB) in China and the EU

Changyu Chen *

Shanghai Ocean University, Shanghai, China

* Corresponding Author Email: 2132301@st.shou.edu.cn

Abstract. This paper offers a thorough analysis of nearly zero energy buildings (nZEB) in many Chinese areas as well as in nations that are members of the European Union (EU). It delves into the various standards and energy-saving technologies employed in these two distinct regions, highlighting both their techniques' commonalities and contrasts in achieving energy efficiency. By comparing the regulatory frameworks and building practices, the research aims to identify best practices that can be adopted across different contexts. Furthermore, the study predicts and analyzes the potential for achieving NZEB goals in the future, considering factors such as policy developments, technological advancements, and market trends. It emphasizes the importance of local conditions in shaping energy-saving measures, suggesting that tailored strategies are essential for effectively meeting the requirements of net-zero energy consumption. The paper ultimately seeks to provide valuable references for policymakers, architects, and builders in both the EU and China, encouraging a collaborative approach to energy efficiency. By fostering a deeper understanding of the prospects and difficulties in implementing NZEB, the study aims to the global conversation about energy-efficient building techniques and the shift to a more sustainable future.

Keywords: net zero energy building, climate zone, nearly zero energy building, renewable energy.

1. Introduction

The notion of net-zero energy building (NZEB) is increasingly important for the new requirement for building energy efficiency today. NZEB stands for “optimally efficient building”, meaning that the total yearly energy consumption of the structure is equivalent to the quantity of renewable energy produced on-site or acquired from off-site renewable energy sources.

A broad grasp of NZEB is necessary for a flexible understanding of clean energy and renewables, as the word may alter between nations and publications. “Net Zero Energy” is frequently used by the European Union and International Energy Agency (IEA); "zero net" is mostly used in the United States [1, 2].

Nearly Zero Energy Building (nZEB), which aims to have all new construction in the area meet nZEB criteria by 2020, is a comparable idea that has been accepted and implemented by the European Union and other signatory nations [3]. While both NZEB and nZEB aim for energy efficiency and sustainability, the key difference lies in how they achieve balance. NZEB aims for a true net-zero status, while nZEB focuses on building energy efficiency [4]. The broad concept of NZEB is shown in Fig. 1, where the energy imported from the grid is represented by the green square and the energy exported to the grid by the red square [5].

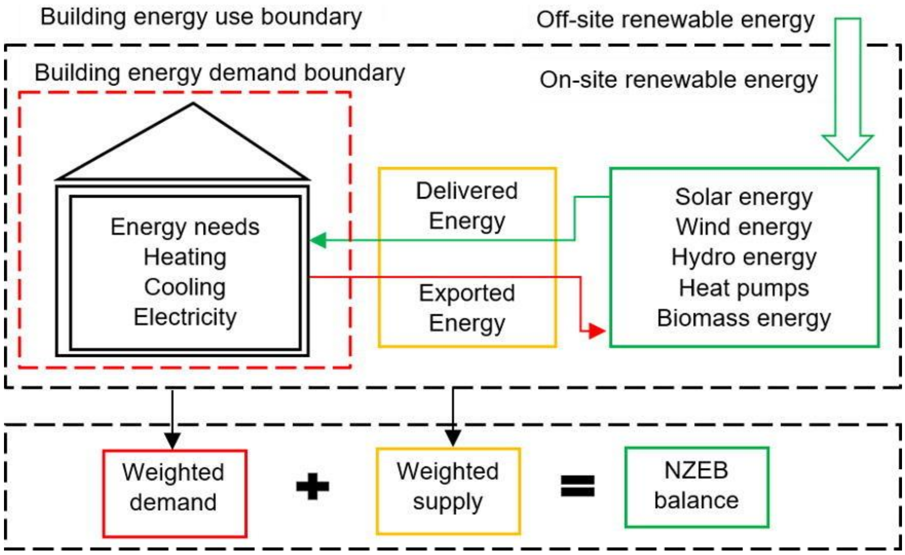

Figure 1. The definition of NZEB [5]

HVAC systems (heating, ventilation and air conditioning) are crucial to how much energy commercial buildings use [6]. As a result, several nations frequently use technology like heat pumps, solar panels, and high-efficiency windows and insulation to attain "net-zero emissions".

The last 20 years have seen a major increase in the adoption of NZEB. In reaction to the energy crisis of the 1970s, interest in renewable energy and energy efficiency technology increased, which was brought on by the oil embargo and rising energy costs. This led to reduce energy consumption in buildings, with early designs incorporating passive solar heating, improved insulation, and building energy-efficient systems [7].

NZEB began to be officially used after the 2000s, at this time DOE (U.S. Department of Energy) started to focus on researching and promoting energy-efficient building practices, which included concepts leading to NZEB. In 2007, the Green Building Council began incorporating NZEB principles into their certification standards, particularly through the Leadership in Energy and Environmental Design (LEED) rating system. Since then, NZEB policies have been implemented in various countries. In 2016, the European Union established a deadline for all new buildings to be nearly zero-energy by the end of 2020, which has had an impact on global trends. The World Green Building Council advocates that all new buildings should operate in a zero-carbon environment by 2030 and that all buildings should achieve zero-carbon operation by 2050. The World Green Building Council favours all new construction to have zero carbon emissions by 2030 and all existing structures to have zero carbon emissions by 2050 [8].

In China, energy consumption and carbon emissions have increased as a result of fast industrialization and urbanization. The Chinese government has implemented various policies aimed at energy efficiency and sustainability. This includes standards for green buildings and investments in renewable energy technologies. China intends to attain carbon neutrality by 2060 and peak carbon emissions by 2030 as part of its commitment to the Paris Agreement [9].

Previous studies have shown that the development of NZEB technologies in Europe is earlier and relatively more mature than that in China. This paper aims to promote the development of NZEB technologies in China by comparing the similarities and differences of NZEB between China and Europe.

2. Overview of typical cases in China

2.1. The classification of climate in China

Thermal design in China is classified into five zones based on climatic changes, as per GB50189-2015. These are: severe cold area, cold region, hot summer and cold winter region, hot summer and warm winter region, and mild region [10]. In 2019, the China Association of Building Energy Efficiency formulated the GB/T 51350-2019 Technical Standard for Nearly-Zero Energy Buildings (nZEB). The standard stipulates that nZEB is a building that provides a comfortable indoor environment with minimal energy consumption and meets the corresponding standards. This is accomplished by making full use of renewable energy sources, optimizing the efficiency of energy equipment and systems through active technological measures, and decreasing the demand for heating, air conditioning, and lighting in buildings through passive building design [11].

2.2. The nZEB standard

Standards of nZEB in China are based on the type of building and the indicator requirements differ from building types. For residential buildings, the combined building energy consumption is ≤55 ($kWh/m^2/year$). For commercial buildings, the overall energy-saving rate should be equal to or greater than 60%. Additional requirements on nZEB can be found in Table 1.

Table 1. nZEB Energy Efficiency Measures for Household Buildings

<table>
<tr><td colspan="2">combined building energy consumption</td><td colspan="5">≤55($kWh/m^2/year$)</td></tr>
<tr><td rowspan="4">building mass performance indicators</td><td rowspan="2">annual heat consumption for heating ($kWh/m^2/year$)</td><td>severe cold region</td><td>cold region</td><td>hot summer cold winter region</td><td>mild region</td><td>hot summer warm winter region</td></tr>
<tr><td>≤18</td><td>≤15</td><td colspan="2">≤8</td><td>≤5</td></tr>
<tr><td>annual heat consumption for cooling ($kWh/m^2/year$)</td><td colspan="5">≤3+1.5× WDH_{20}+2.0× DDH_{28}</td></tr>
<tr><td>building airtightness (number of air changes N_{50})</td><td colspan="2">≤0.6</td><td colspan="3">≤1.0</td></tr>
<tr><td colspan="2">renewable energy efficiency</td><td colspan="5">≥10%</td></tr>
</table>

High-performance thermal insulation, premium doors and windows, careful thermal bridge management, suitable airtightness design, high-efficiency energy recovery ventilators, effective cooling and heating systems, and renewable energy sources are among the crucial technical components needed to obtain NZEB status [12].

The “14th Five-Year Plan” in China is entering a crucial phase. By 2025, every new building in cities and towns will be built as a green building, under the strategy for building energy efficiency. This will provide a strong basis for the building industry in both urban and rural areas to achieve carbon peaks by 2030.

2.3. Overview of cities in China

Nearly Zero Energy Building have been constructed on a large scale based on existing technologies and current codes and standards in China. However, these are not yet common for typical case studies. Considering the actual situation and expectations for technological advancements, it is believed that nZEBs have the potential to meet the NZEB standard in the future. According to this guideline, the yearly total energy used, whether from on-site or off-site renewable energy sources, is equal to the quantity of renewable energy created. Therefore, this section focuses on awakening nZEB buildings.

Following the nZEB technology standard in 2019, it has been developed on a large scale in various regions of China. The distribution of such buildings within different thermal climate zones in China is presented in Fig. 2. Among all climate zones, about 70% of these buildings are located in cold region. On the other side, the hot summer warm winter area, hot summer cold winter region, and severe cold region make up around 10% of the nZEB. This means that the potential to help create almost energy-zero buildings in these regions is high. In Fig. 3, the number of nZEB in major cities showed by the end of 2022 compared to the number required by the 14th Five-Year Plan [13].

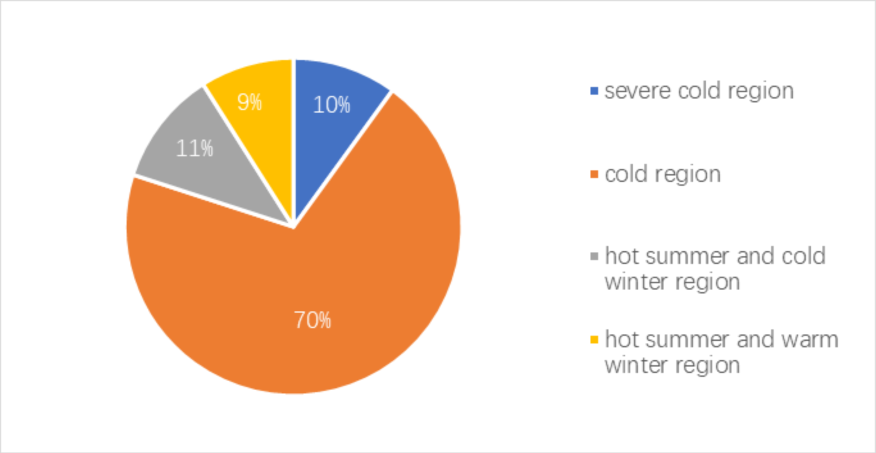

Figure 2. Distribution of nZEB in different climate zones (2019) [13]

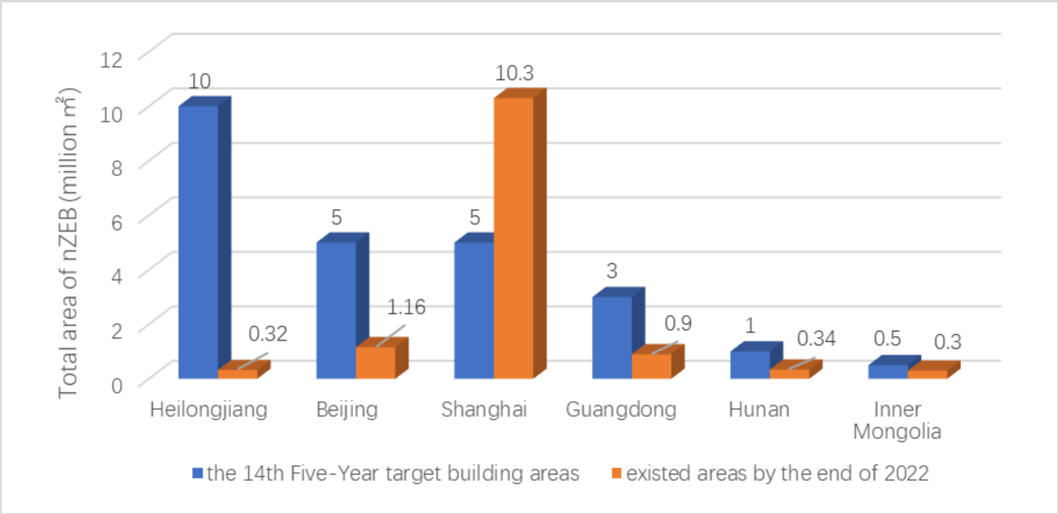

Figure 3. nZEB existed areas and target areas (2022) [13]

It is evident that all provinces and cities except Shanghai fall short of the required standards. As of the end of 2022, the total nZEB area is highest in Shanghai (10.3 million square meters), followed by Beijing (1.16 million square meters) and Guangdong Province (0.9 million square meters). This indicates that highly developed first-tier cities like Beijing, Shanghai, and Guangdong have significant potential for developing nearly Zero Energy Buildings. Conversely, less developed regions will face greater challenges in meeting the required floor area by 2025, considering factors such as population, geography, and development patterns. Based on this trend, Shanghai could emerge as the primary nZEB city in China.

3. Overview of typical cases in EU regions

3.1. The classification of climate in Europe

Based on seasonal patterns of temperature and precipitation, Europe's climate is classified into five broad categories by the Köppen climate classification system, which are: tropical, arid, temperate, continental and polar region. Each main group has several subgroups. In the process of creating nZEB, Ecofys has optimized the building climate classification further.

Five European climate zones were classified using total solar radiation, heating days, cooling days, and cooling capacity with night ventilation. This classification serves as a useful reference for defining nZEB in various European countries. The specific definition of each climate zone can be found in Table 2 [14, 15].

Table 2. nZEB climate zones in EU

zone	cities	Köppen
Zone 1	Athens, Palermo	Csa
Zone 2	Lisbon, Madrid	Csa Cfb
Zone 3	Milan, Venice	Dfb
Zone 4	Berlin, Paris	Cfb/Dfb

3.2. The nZEB standard

By 2030, compared to 2015, the Energy Performance of Buildings Directive seeks to cut greenhouse gas emissions in the construction industry by at least 60%. In terms of energy efficiency, the European Commission has stated that reaching the 2030 GHG reduction target in a cost-effective manner would necessitate an increase in energy savings of around 25% [16]. The nZEB standards vary among European countries, as shown in the statistics (Fig.4) for different European countries. The data was collected in 2023, therefore the information presented in this figure is relatively accurate. This is also an important reference for the implementation of the nZEB standard [17].

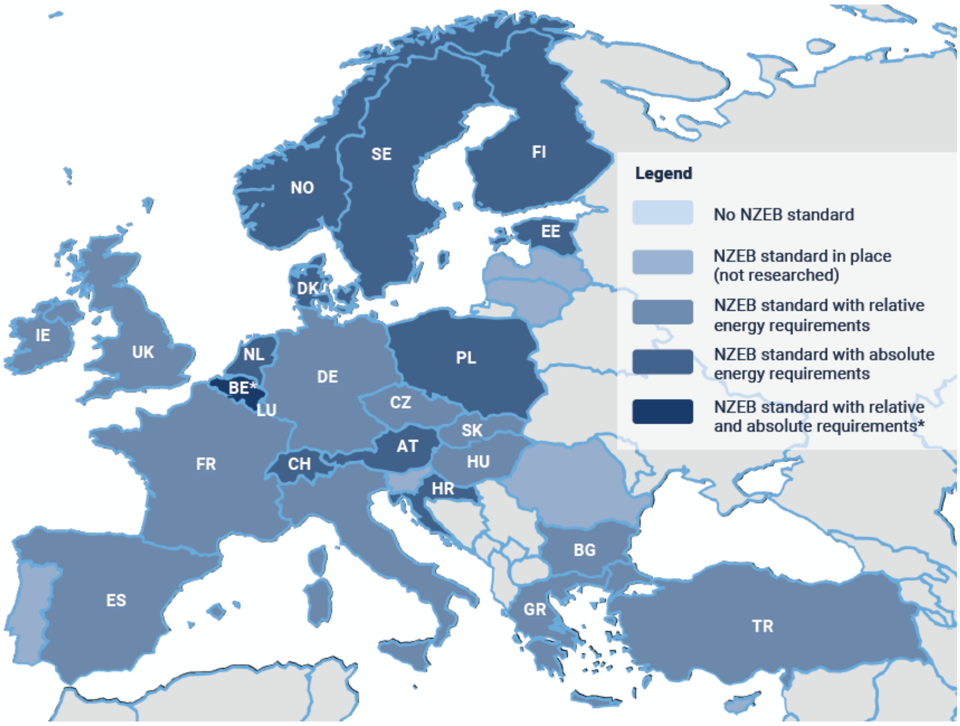

Figure 4. nZEB standards across Europe (2023) [16]

The standards of nZEB from various climatic zones have been gathered by recent investigations and are shown in Table 3 [18].

Table 3. nZEB targets in residential buildings depending on the climate zone

climate zone	nZEB targets in 2016 ($kWh/m^2/year$)
Zone1&2	35-100
Zone3	20-125
Zone4	15-70

3.3. Overview of European countries

One research in some East European countries (Poland, Slovakia, Hungary, Romania, Bulgari) is shown in Table 4. Another set of data from Southern European countries is presented in Table 5 [19, 20]. In Table 4, it is evident that all countries except Romania have zero energy efficiency for cooling and heating throughout the year. These four countries do not utilize any Renewable Energy Resources

(RES) for cooling and heating. The energy performance of nZEB ranges from $32kWh/m^2/year$ (Slovakia) to $100kWh/m^2/year$ (Hungary), with Romania having the highest emissions at 217kWh per square meter per year. In Table 5, the demand for renewable energy is over 50% in Southern European countries, except for Greece. Compared to the Eastern European countries, their primary energy use is generally low, ranging from $33kWh/m^2/year$ (Portugal) to $120kWh/m^2/year$ (Italy). By comparing these values with Table 3, the primary energy emission in Romania and Poland is higher than the nZEB standard. The other countries are under the maximum requirement.

Table 4. nZEB in Eastern Europe

	energy efficiency min.					
country	energy for cooling ($kWh/m^2/year$)	energy for heating ($kWh/m^2/year$)	primary energy ($kWh/m^2/year$)	RES	climate zone	latitude
Slovakia	none	none	32-54	no	1	48.8°N
Hungary	none	none	85-100	no	2	46.07°N
Romania	70	20	93-217	>30%	3	45.60°N
Bulgaria	none	none	95	no	3	42.50°N
Poland	none	none	65-75	no	4	54.30°N

Table 5. nZEB in Southern Europe

	energy efficiency min.					
country	energy for cooling ($kWh/m^2/year$)	energy for heating ($kWh/m^2/year$)	primary energy ($kWh/m^2/year$)	RES	climate zone	latitude
Spain	10	10	60	60%	2	40.40°N
Portugal	15	40	33	50%	2	38.80°N
Italy	15	15	120	50%	3	45.20°N
Greece	80	80	100	25%	1	38.00°N
France	5-20	5-20	50	50%	4	48.80°N

4. Comparison of China and EU regions

4.1. nZEB-Technologies

There are now a lot of nZEB technologies available. In the EU, a few energy-saving technologies are frequently cited as crucial nZEB components. Table 6 lists the specific needs in detail [21]. It demonstrates that electric storage technologies have the highest potential reductions, with a 62.7% reduction in 2030 and a need to reduce to 77.7% by 2050.

This indication echoes today's global requirement to reduce carbon emissions. Boiler technology, on the other hand, is relatively mature in Europe and its potential reduction is lower, requiring a reduction to 11.1% by 2050.

Table 6. Possibility of cost savings between 2050 and 2030

Technology	until 2030	until 2050
Solar thermal	9.1%-23.9%	22.0%-50.8%
Aerothermal heat pump	4.8%-21.6%	11.0%-43.9%
Ground source heat pump	5.9%-25.8%	7.9%-33.4%
Electrical storage	34.9%-62.7%	47.9%-77.7%
photovoltaics (PV)	20.0%-29.0%	41.0%-55.5%
Air conditioner	9.3%-25.2%	17.8%-44.3%

The Chinese government has created pertinent green building indicators under the “14th Five-Year Plan”. Table 7 indicates the general and specific indicators in this period. It is important to note that this Plan calls for 0.5 billion square meters of floor space for nZEB, which is a significant increase of 0.1 billion square meters of nZEB by 2020 [22]. The quantity of these buildings required has increased fourfold. Consistent with European countries, the largest reduction in electricity consumption was made, up to 55%.

Table 7. General and Specific Indicators for Building Energy Efficiency

	until 2025	unit of measure
total primary and secondary energy consumption for building operations	11.5	billion tons of standard coal
construction of nearly-zero-energy building area	0.5	billion square meters
Electricity consumed in building energy consumption	55%	—

4.2. Energy consumption

The metrics mentioned above for nZEB buildings and the actual data for each region are important benchmarks for achieving NZEB in the future. By analyzing the differences in values and the rate of changes from year to year, future trends in energy emissions can be predicted. The data collected by company BP in Table 8 shows the comparison of primary energy in China with EU countries, specifying the expected emissions in 2022 and beyond, and the difference with the net zero indicator. Taking into account the different forms of energy composition in developed and developing regions, as well as relevant policy standards, the NZEB standards by 2050 will be site-specific. China's primary energy use today is 146 EJ, with a projected standard of 94 EJ by 2050, while the EU countries' primary energy use in 2022 is 55 EJ, with a projected standard of 28 EJ by 2050. In comparison, neither the EU nor China will be able to meet the standard value for primary energy emissions in 2050 based on the projected trends.

Table 8. Primary energy (EJ^*) in EU and China

Country	2022	2050 current trajectory	2050 Net Zero	Change 2022-2050 current trajectory	Change 2022-2050 Net Zero
EU	55	40	28	-1.1%	-2.3%
China	146	128	94	-0.5%	-1.6%

$*$ EJ represents 10^{18} joules

Additionally, Fig.5 and Fig. 6 illustrate the consumption of energy other than primary energy in the EU and China regions, at the end of 2020, focusing on hydropower and renewable energy. Renewable energy is specifically categorized as solar, wind and biomass energy [23, 24]. China's overall consumption of hydropower and total RES is higher than that of all EU countries. It is possible that China's large population and expansive land area contribute to the higher total energy demand compared to European countries. Additionally, China's energy consumption from hydropower (11.74 EJ) exceeds its consumption from total renewable energy sources (7.79 EJ). In contrast, European Union countries consume more energy from renewable sources than from hydropower at 6.97 EJ.

The difference in renewable energy sources (RES) between China and the EU is worth analyzing. China's consumption of solar PV systems and wind energy is higher than that of the EU countries, at 253.8GW and 282GW, respectively. In addition to the use of biomass fuels (56kBOE/d), it's worth noting that biomass use in the EU countries is much higher than that of PV and wind energy, at 294kBOE/d.

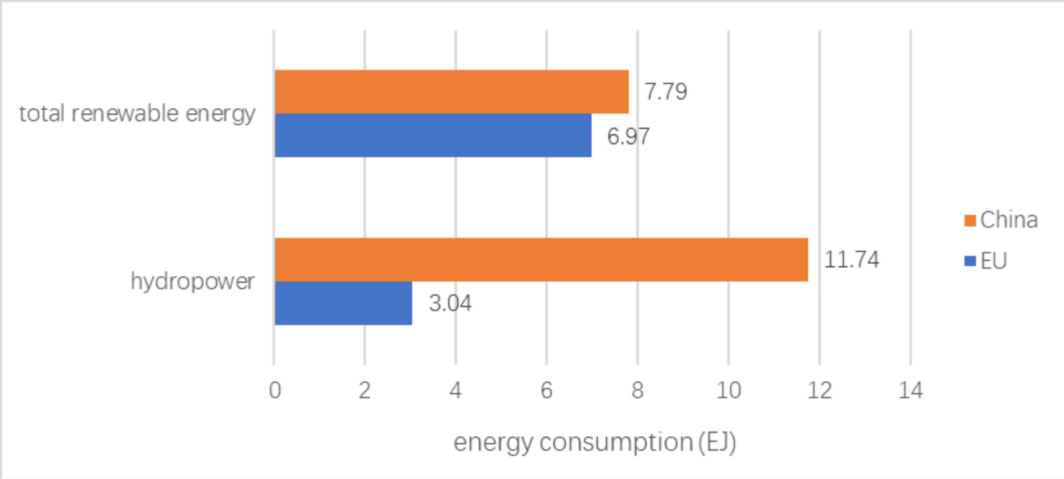

Figure 5. Consumption of energy in the EU and China (2020)

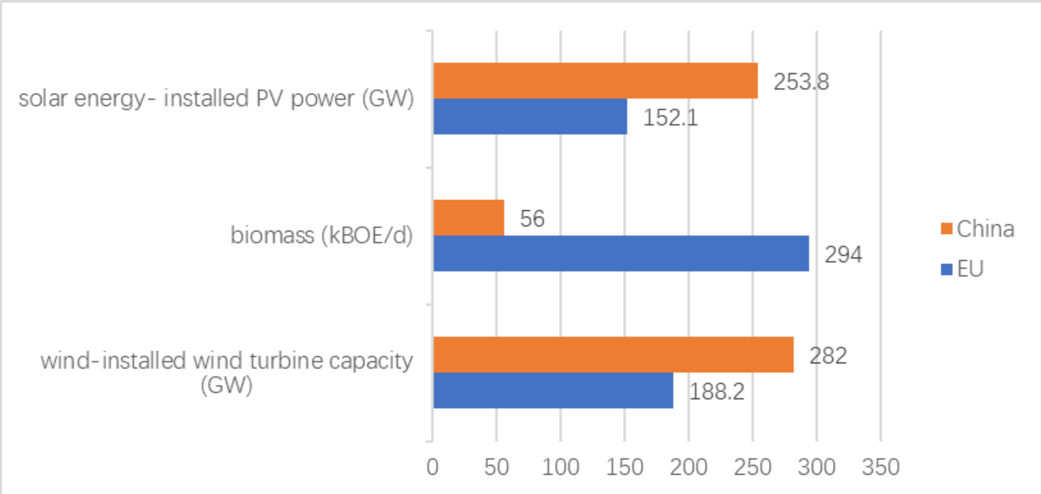

Figure 6. Uses of RES in the EU and China (2020)

5. Conclusion

In general, efforts are being made by China and the EU to switch to NZEB. Reaching virtually zero energy buildings (nZEB) at a certain scale is the first stage, followed by progressing from nearly zero to net zero. During this period, in order to meet the nZEB standard, by using various technological approaches, the EU and China are both lowering carbon emissions throughout the course of a building's life cycle. From the above studies, it is clear that both the EU and China are stepping up their efforts to curtail electricity consumption. In order to save energy and reduce emissions, adjustments have also been made to the electrical supply. For example, more renewable energy sources have been substituted for primary energy usage. China is presently at a crucial point in the construction of almost zero-energy buildings, whereas most EU member states have developed systems and standards for this kind of building. Nonetheless, EU nations may encounter difficulties maintaining and modernizing current structures in order to realize net-zero energy targets because of variations in building development timelines. In contrast, the concept of nZEB is still unclear in many underdeveloped regions of China, and its standards vary depending on each region’s thermal characteristics. There are not many of these kinds of green buildings, and there is no comprehensive data source available in the short term. Thus, we can support NZEB's expansion in China and work toward NZEB's ultimate goal by looking at the experiences of European nations and keeping an eye on NZEB development in the EU.

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