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A review of net zero energy buildings in hot and humid climates: Experience learned from 34 case study buildings

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ABSTRACT

Sustainable development in the building sector requires the integration of energy efficiency and renewable energy utilization in buildings. In recent years, the concept of net zero energy buildings (NZEBs) has become a potential plausible solution to improve efficiency and reduce energy consumption in buildings. To achieve an NZEB goal, building systems and design strategies must be integrated and optimized based on local climatic conditions. This paper provides a comprehensive review of NZEBs and their current development in hot and humid regions. Through investigating 34 NZEB cases around the world, this study summarized NZEB key design strategies, technology choices and energy performance. The study found that passive design and technologies such as daylighting and natural ventilation are often adopted for NZEBs in hot and humid climates, together with other energy efficient and renewable energy technologies. Most NZEB cases demonstrated site annual energy consumption intensity less than 100 kW-hours (kWh) per square meter of floor space, and some buildings even achieved "net-positive energy" (that is, they generate more energy locally than they consume). However, the analysis also shows that not all NZEBs are energy efficient buildings, and buildings with ample renewable energy adoption can still achieve NZEB status even with high energy use intensity. This paper provides in-depth case-study-driven analysis to evaluate NZEB energy performance and summarize best practices for high performance NZEBs. This review provides critical technical information as well as policy recommendations for net zero energy building development in hot and humid climates.

1. Introduction

The world shares the same prevailing mission: to reduce energy consumption and pursue a sustainable development path for all. Current building energy use is significant. According to the Energy Information Administration (EIA), the building sector consumed more than 20% of the delivered energy worldwide in 2015, and this proportion will remain the same in 2040 [1]. Meanwhile, building-related emissions have increased by 45% since 1990 [2]. In the United States, the building sector consumes more energy than any other sector — about 39% of the country's total primary energy use in 2017 [3]. However, these significant proportions of energy consumption and emissions harbor great potential to contribute to energy conservation and carbon emission reduction. Therefore, improving building energy efficiency and lowering the associated carbon emissions is a key strategy for addressing global issues such as energy consumption reduction, mitigating climate change, and reducing the carbon footprint of human activities.

Recently, net zero energy buildings (NZEBs) have gained increased popularity in the building industry in many countries as a promising solution to reduce building energy consumption. The concept of self-sufficient and energy autonomous construction has been popular for a long time for applications under severe conditions, such as solar-powered satellites in space or stand-alone construction in remote areas

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Table 1
Summary of current policies for NZEBs in different countries and regions.

Country/Region	Organization	Program	Content	Year	Ref.
Europe	Directive on Energy Performance of Buildings (EPDB)	ZEBRA 2020	New buildings are to be nearly zero energy from 2020.	2010	[7]
Belgium	Brussels Capital Region Ministry of Environment	Brussels Passive House Law 2011	New construction or major renovation of a dwelling, office or school must comply with the passive standard (nearly zero energy) from 2015.	2011	[8]
Germany	EPDB	Act on the Promotion of Renewable Thermal Energy	Aim of achieving an almost climate-neutral building stock by 2050	2010	[176]
France	Ministry of Environment, Energy and the Sea	Act on Energy Transition for Green Growth	New buildings should be energy positive by 2020.	2015	[9]
Denmark	The Ministry for Climate, Energy and Buildings	Building class 2020	Public buildings and private buildings are to be nearly zero energy buildings by 2018 and 2020, respectively.	2015	[10]
USA	Office of the Law Revision Counsel	The Energy Independence and Security Act of 2007	50% of new commercial buildings by 2040 and all new commercial buildings by 2050 should be zero energy.	2007	[11]
USA	U.S. Department of Energy (DOE)	The Building Technologies Program	Realize NZEBs at low incremental costs by 2025.	2008	[12]
USA	The California Public Utilities Commission (CPUC)	Zero Net Energy Action Plan	New residential and commercial construction will be NZEBs by 2020 and by 2030, respectively. 50% of commercial buildings will be retrofit to be NZEBs by 2030, and 50% of new major renovations of state buildings will be NZEBs by 2025.	2015	[13]
USA	The New York State Energy Research and Development Authority	Ultra-low energy buildings in a high-density urban environment	Beginning in 2025, all large new buildings would be required to build to very-low energy design targets.	2014	[175]
Canada	British Columbia (BC) Energy Step Code Council	BC Energy Step Code	New buildings must be “net-zero energy ready” by 2032.	2017	[14]
Canada	The City Planning Division of Toronto	Zero Emissions Buildings Framework	The municipality committed to adopt Tier 2, 3, or 4 for all city-owned development with nearly zero emissions standards by 2026.	2018	[175]
UK	Ministry of Housing, Communities & Local Government	National Planning Policy Framework	All new homes should be zero carbon from 2016, and all other buildings from 2019.	2012	[15]
Japan	Ministry of Economy, Trade and Industry (METI)	Strategic Energy Plan 2014	Newly constructed public buildings and standard houses are to be zero-energy buildings voluntarily by 2020. Newly constructed buildings and houses are to be zero-energy buildings voluntarily by 2030.	2015	[16]
Korea	National energy roadmap & Zero energy building certification	Building Energy Efficiency Program	New building constructions should have net zero energy consumption and non-residential buildings should have an energy saving rate of 60% by 2025.	2012	[178]
South Africa	C40 & Sustainable Energy Africa (SEA)	C40 South Africa Buildings Program	Energy efficiency policies and programs towards a net zero carbon performance for new buildings in South African cities are to be developed and implemented by 2020.	2018	[17]
Sweden	Stockholm	Buildings in the context of a fossil fuel free city	All development on city-owned land must comply with a maximum energy use intensity, or Specific Purchased Energy, of 55 kW-hours per square meter per year (kWh/m^2/year). Buildings this efficient can be considered to be zero or nearly zero energy buildings by 2040.	2010	[175]
China	Ministry of Housing and Urban-Rural Development	The 13th five-year plan for building energy conservation and green building development	The construction of demonstration projects of ultra-low-energy and near-zero-energy buildings will reach more than 10 million square meters by 2020.	2017	[175]
Australian	National Strategy on Energy Efficiency	ZCA Buildings Plan	Australia's emission goal is to reduce emissions to 26%–28% on 2005 levels by 2030.	2009	[179]
Singapore	Building and Construction Authority	Building Energy Efficiency (BEE) R&D Roadmap and Solar PV Technology Roadmap	BEE to achieve improvements in the Energy Efficiency Index (EEI) by 40%–60% over 2013 best-in-class buildings by year 2030; Super Low Energy (SLE) to achieve improvements in the EEI by 60% over 2005 industry levels by 2018 and 80% by 2030.	2014	[180]
Malaysia	The Sustainable Energy Development Authority Malaysia	Zero Energy Building Facilitation Program	Intends to reduce its greenhouse gas (GHG) emissions intensity of GDP by 45% by 2030 relative to the emissions intensity of GDP in 2005.	2018	[181]
Association of Southeast Asian Nations (ASEAN)	The ASEAN Member States	ASEAN Energy Awards	Zero Energy Building Added to ASEAN Energy Awards 2019	2019	[182]

where facilities cannot be connected to power grids. Ionescu et al. [4] reviewed the genesis of the energy efficient buildings in history. The first fully functioning passive house (a nearly zero energy building) was actually not a house, but a polar ship named the Fram of Fridtjof Nansen in 1893 [5]. In building science, the term "zero-energy building" also is not recent. As early as 1976, researchers in Denmark proposed the term "zero energy house" for the first time by conducting research on solar energy for heating buildings in cold winters [6]. The concept of an NZEB has been developed ever since, and recently it has become mainstream. This paper will use the term "net zero energy buildings (NZEBs)." Table 1 summarizes the current policies and regulations for NZEBs in various countries. Most are promulgated in Europe and the United States, leading to the rapid and large-scale development of NZEB projects in these areas. At this stage, few relevant policies exist in hot and humid regions. Thus, there is an immediate need to conduct a comprehensive review of NZEBs in hot and humid climates.

The climate is playing a significant role in energy-efficiency systems and energy consumption patterns in building science; therefore, this study reviewed key NZEB design issues for hot and humid climates specifically, and analyzed their feasibility by investigating 34 actual NZEB projects as field experiences for classifying the climatic-responsive design strategies and options in similar climatic conditions.

The targeted climate features are often described as hot, humid, cooling-dominated, hot summer/warm winter (China) [18], high humid summer/warm winter (Australia) [19], hot-humid zone below the "warm-humid" line [21], and tropical/subtropical climates, which include most of Southeast Asian countries, and some of Middle/South American and African countries. More widely, the climate zones this paper is targeting include most parts of India, Southeast Asian countries, Central America, South America except its southern areas and majority parts of Africa [22]. Table 2 summarizes climate indicators of hot and humid regions in representative countries and regions. Taking the climate indicators of different countries into account, in this article the term "hot humid climate" is defined as an area where the cooling degree days (CDD) (10 °C) for 3,000 or more hours and the average temperature in the coldest month are greater than 10 °C, and precipitation is relatively abundant and dry bulb humidity is greater than 50% usually. According to these meteorological parameter settings, Fig. 1 can show clearly the extent and distribution of hot and humid climate regions in the world map.

Existing reviews in the field of NZEBs have dealt with worldwide NZEB developments [23–25], presented general overviews of the design optimizations, or focused on specific NZEB technologies. However, little research has drawn on any systematic research of NZEBs in hot and humid climates, especially based on experience of design and operation of actual case studies. Therefore, this paper presents a comprehensive review of NZEBs in hot and humid climates by summarizing experience and best practices from real world case studies. Its goals are to present features of current NZEB development in hot and humid climates, review climate-responsive NZEB designs and technologies, and analyze building energy performance and establish best practices for NZEB design and technology choices in hot and humid climates.

Section 1 introduces the background of NZEB development and the existing policies of mainstream countries. Section 2 reviews the key drivers of NZEB development in hot and humid regions, focusing on the economy, environment, cooling demand and policies. Section 3 introduces the definition of NZEBs in different countries and provides a summary of case studies used by this paper. Section 4 conducts case study review and summarizes design features and technology choices of NZEBs in hot and humid climate zones. Section 5 examines NZEB energy performance by using annual, monthly and typical days' energy data collected from case studies. Based on the analysis, recommendations are given to develop high energy performance NZEBs with a focus on maximizing energy efficiency.

2. Background of NZEB development in hot and humid climate regions

There is a critical need to review and summarize net zero energy buildings due to economic development, increase of cooling demands, environment and climate change, cultural characteristics, and geography.

NZEBs are growing rapidly in developed countries, while facing challenges and barriers in developing countries. More than 90% of over 300 NZEB projects listed in the International Energy Agency (IEA) Solar Heating and Cooling Programme (SHC) Task 40 world map are located in the developed regions of the European Union (EU) and U.S. [26]. Only 11 of them are in hot and humid regions, and only three cases are selected into a report of shortlisted 30 NZEBs in this program with enough data and technical information on NZEBs characteristics and energy performance. Moreover, these three cases are all from developed countries. The imbalance of these NZEB developments is due to economic causes, since high initial investment and long payback periods pose the main barriers to NZEBs in developing regions [25]. Under these circumstances, it is important for developing countries to focus on passive strategies with relative low initial investments and cost-effectiveness strategies with short payback periods to promote the development NZEBs in hot and humid regions. It is important to evaluate cost-effective analysis of technologies employed in net zero energy buildings, especially for developing regions [27].

Policies and incentives play a vital role in promoting NZEB

Table 2
Climate indicators of hot and humid regions in different countries.

Country/Region	Climate zone name	Main climate indicators	Ref
China	Hot summer and warm winter zone	The average temperature in January is greater than 10 °C; the average temperature in July is 25 °C–29 °C	[18]
Australia	High humid summer/warm winter	Highly humid with a degree of "dry season," high temperatures year round, minimum seasonal temperature variation, and lowest diurnal temperature range.	[19]
United States	Extremely Hot – Humid (Zone 0A)	6,000 < CDD10 °C	[20]
	Very Hot – Humid (Zone 1A)	5,000 < CDD10 °C ≤ 6,000	
	Hot – Humid (Zone 2A)	3,500 < CDD10 °C ≤ 5,000	
	Hot-humid zone below the "warm-humid" line (the portions of IECC zones 1, 2, and 3)	Generally defined as a region that receives more than 50 cm (cm) of annual precipitation and where one or both of the following occur: A 19.5 °C or higher wet bulb temperature for 3,000 or more hours during the warmest six consecutive months of the year; or A 23 °C or higher wet bulb temperature for 1,500 or more hours during the warmest six consecutive months of the year.	[21]
India	Cooling and Dehumidification (Very high cooling demand)	CDD10 °C ≥5,000 & HDD18 < 1,000 & RH ≥ 5	[22,175]
Brazil	Cooling and Dehumidification (Very high cooling demand)	CDD10 °C ≥5,000 & HDD18 < 1,000 & RH ≥ 5	[22]

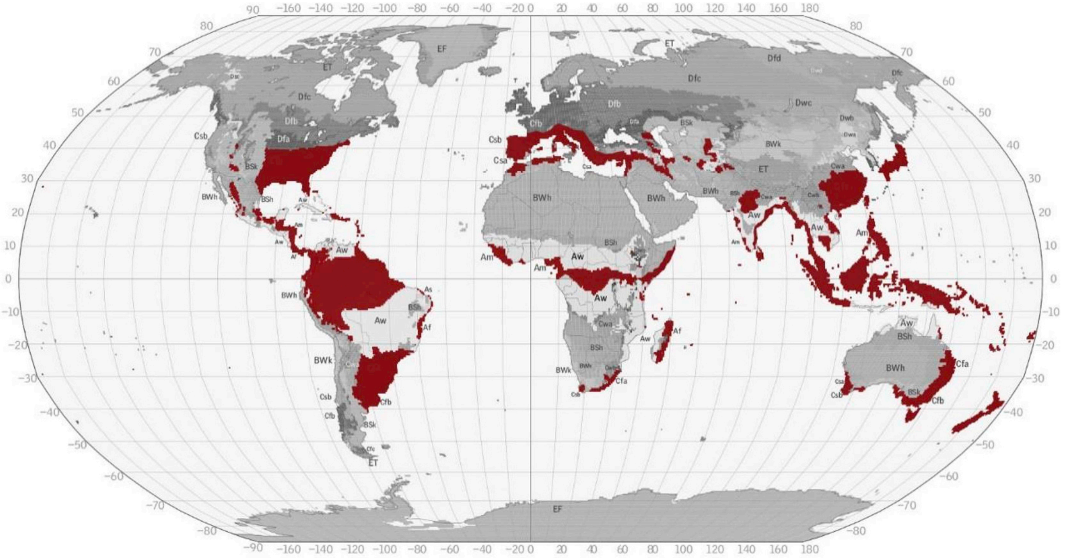

Fig. 1. Hot and humid climate regions in the world.

development in hot and humid regions. Table 1 summarizes the policies of current zero-energy buildings worldwide. Very few countries or regions in hot and humid climates have NZEB policies. In developing countries in the tropics, however, the practice of constructing sustainable and climate-responsive buildings with low carbon emissions and high building performance, such as traditional shop houses with courtyards in Southeast Asia, has a long history [28]. Nowadays, the lack of showcases, guidelines and standards results in less common net zero energy building development in these areas than in developed countries.

Continuous urbanization and residents' rising income levels in developing tropical countries will require improvement in buildings' indoor thermal comfort and increased cooling energy demands. The cooling demands of fast-growing markets among hot and humid regions such as India and Indonesia may increase by 5% or more annually over the next ten years [29]. Room air-conditioner shipments have surged from 2.76 million in fiscal year 2011–12 to 7.32 million in fiscal year 2018–19, and the rate of growth also has been accelerating year by year in India [30]. Climate change and global warming is another key reason of growth in cooling energy demand. The Organization for Economic Cooperation and Development (OECD)/IEA report [31] *The Future of Cooling* pointed out that if no measures are taken, the cooling demand in buildings will more than triple by 2050, making it equivalent to China's current electricity demand. These cooling demands raise more stringent requirements for future NZEB development in tropical areas, thus a review of designs and technologies to slow cooling load increases and meet people's thermal comfort requirements becomes critical.

Architectural features also distinguish buildings in hot and humid regions from other climates. Buildings in tropical areas are often designed to enhance the interactions between indoor and outdoor climates, especially during non-air-conditioning seasons; whereas buildings in cold climates often emphasize an air-tight building envelope system. Thus, it is important to design an NZEB to employ passive features such as natural ventilation and daylighting and reduce building energy use. The indoor comfort criteria also can be different in naturally ventilated buildings. The "adaptive thermal comfort model" for natural or hybrid ventilation environments is needed for NZEBs in a tropical climate [32–34], to maximize natural ventilation and save energy. As NZEBs become more interactive with the outdoor environment, it can greatly influence people's choices of NZEB technologies and comfort satisfaction [35–39]. People who live in areas with significant environmental problems are often reluctant to accept poor indoor environments and are more supportive of green technologies [40].

There are many island regions in tropical areas. Because islands are particularly vulnerable to climate change and sea level rise, developing NZEBs is an effective way to improve building resilience for islands and small-scale countries, and to enhance local energy independence. The concept of a "zero energy island" (NZEI) [41], where the scope of the energy balance is extended to islands, is a more advanced and ambitious goal for hot and humid islands to meet to achieve energy independence. More important, to tackle climate change in developing economies, research should not only just focus on buildings' operational energy but also on embodied energy when planning NZEB development [176].

3. Definitions and case study of NZEBs

3.1. NZEB definitions

Previous studies have reviewed the different definitions and energy performance calculation methodologies of NZEBs in various countries and regions [42–45]. Although many efforts have been made to establish an internationally agreed understanding of NZEBs, and to evaluate NZEBs based on a common methodology [46], there is not yet a unified definition of NZEBs. Delia D'Agostino et al. compared the definitions of the NZEB in EU and U.S., and also offered a proposal for clarifying the meaning of near zero, zero, and plus energy buildings [173]. Zhang et al. reviewed and compared NZEB definitions in leading world regions [43], and pointed out two key differences in definitions. One is whether the plug load in the end use should be counted, and the other is whether off-site renewable energy can be counted. If the regulation and policy only targets the building construction itself, off-site renewable energy should not be considered. Giving too much credit to off-site renewable energy generation may diminish a building's efforts to include energy efficiency and on-site renewable energy generation. Since it is difficult to unify standards globally, the National Renewable Energy Laboratory (NREL) proposes a diverse set of "net zero energy" definitions and encourages architects, developers and stakeholders to choose the indicators that best suit their projects [42]. This attempt provides a direction for systematic NZEB definitions instead of a single definition. In this study, we follow the U.S. Department of Energy (DOE) definition of an NZEB as "an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy" [47]. Moreover, Pless and Torcellini [48] defined four types of NZEBs: A, B, C and D, based on location of renewable energy generation as illustrated by Fig. 2. An

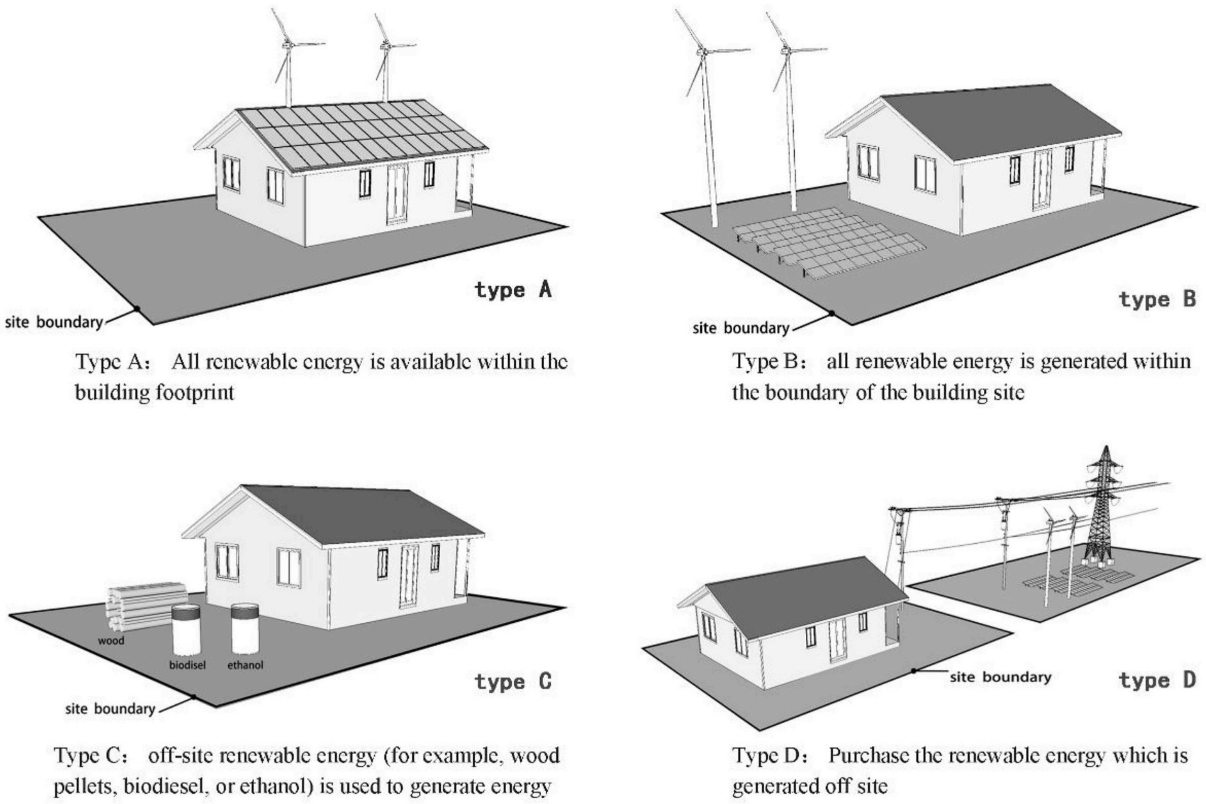

Fig. 2. Four types of NZEBs: A, B, C and D.

important criteria of the U.S. DOE and Pless et al. definitions is to evaluate where renewable energy generation comes from — whether it is on-site renewable generation or off-site renewable procurement. Here, Pless et al. defines types A and B as NZEBs where all the renewable energy is available on site; while types C and D refers to buildings that mainly use off-site renewables. The definition further distinguishes a type A NZEB as one where renewable energy generation only comes from a building's footprint, while type B uses renewable energy generation that comes from within a building's footprint and/or from its site. Based on this definition, this paper lists all 34 cases as type A or B net zero energy buildings in Table 3, as all the renewable energy is available on site. Types C and D were not considered in this study. The U.S. NZEB definition developed by U.S. DOE and Pless et al. is similar to another NZEB definition discussed by D'Agostino et al. [173], as these definitions all use on-site and off-site renewable generation as the major distinction to categorize different types of NZEBs. In this study, we also considered plug load energy use to be a part of building energy performance, since it is relevant to user behaviors and NZEB operation and management.

To apply the NZEB definitions, some countries have initiated their standards and guidance development process to guide NZEB development. Noticeably, The American Society of Heating Refrigerating and Air-Conditioning Engineers (ASHRAE) has been working with U.S. stakeholders to develop an NZEB deign guideline [49]. The guideline, based on ASHRAE's previous work on the advanced energy design guideline (AEDG), is intended to provide building designers and operators on NZEB technologies choices and operation parameters. Also, China has initiated its nearly zero energy building standard development to guide its ultra-low energy building and high performance building development process [50].

3.2. NZEB case studies in hot and humid climate zones

There are a few research projects on NZEB case studies. One is from the New Building Institute (NBI) in the United States. Their latest Getting to Zero Status Update and Zero Energy Buildings List provides 482 certified, verified and emerging zero energy projects in North America [51]. Another is the IEA SHC Task 40 “Towards net zero energy solar buildings” under the framework of the IEA solar heating and cooling program [73]. Two outcomes of the IEA SHC Task 40 are a world map of more than 300 NZEBs published online [26] and a case study report of 30 shortlisted NZEBs where mandatory technical documents are available [74]. Furthermore, the International Living Future Institute (ILFI), which provides NZEB certification, has a database of NZEBs mainly in the North America region [75].

In the IEA SHC Task 40 project, three NZEBs in hot and humid climates are identified, and these are shortlisted in a case study report. In the NBI list, 20 NZEBs in hot and humid regions are identified. Other small-scale NZEB case studies [27,74] or non-NZEB but energy-efficient building studies in hot and humid areas can be found in the literature as well, including studies in Darwin, Australia [77,78]; Kuala Lumpur, Malaysia [77]; Hong Kong [79–83]; and the United States [84,85]. In sum, 34 cases of real-world net zero energy projects in hot and humid climates were selected for this study. Based on the definition discussed above, we reviewed publicly available databases and literature to extract these 34 NZEB cases in hot and humid climates for this study [51–65,76].

All cases have the solar photovoltaic (PV) system on the roof and/or integrated on facades. Most cases are new construction, with only 5 of the selected 34 NZEBs — Anna Marina Historic Village, Leon County Cooperative Extension, Zero Energy Building BCA Academy, Vallhones Prototype 1, and the ENERPOS building — being retrofit projects. Most of the 35 cases are low-rise non-residential projects in hot and humid climates, except one case in China: the Xingye HQ building in Zhuhai, a high-rise office building. LEED platinum or gold certifications are commonly found in most cases. As the primary research goal was to investigate NZEBs in hot and humid climates, other climate regions such as heating dominated climates were not considered.

Table 3
Case studies of net zero energy buildings in hot and humid climate zones.

Name	Reference	Climate zone ASHRAE	Year Built	LEED Certification	Building type	Location	Size (m^2)	Stories	CDD/HDD (based on 65 °F)	Precipitation (mm)	Biomass CHP	Biomass-fired boilers	Geothermal Heat pump
TD Bank Branch - Ft. Lauderdale	[51]	Zone 1	2011	LEED Platinum	Retail bank/ office	Ft. Lauderdale, FL	370	1	4098/178 [66]	1579 [68]			
PNC Net-Zero Branch	[51,52]	Zone 1	2013	LEED Platinum	Retail bank/ office	Ft. Lauderdale, FL	442.8	1	4098/178 [66]	1579 [68]			
Suncoast Credit Union - Bushnell Service Center	[51]	Zone 2A	2015	N/A	Office	Bushnell, FL	348	1	3125/789 [66]	1315 [68]			✓
Anna Maria Historic Green Village	[51]	Zone 2A	2012 Retrofit	LEED Platinum	Commercial/ multi-use	Anna Maria Island, FL	743	1–2	3324/556 [66]	1346 [68]			✓
Leon County Cooperative Extension	[51]	Zone 2A	2012 Retrofit	N/A	Office	Tallahassee, FL	1208	1	2551/ 1664 [66]	1475 [68]			✓
Sarasota Audubon Nature Center	[51]	Zone 2A	2015	LEED Gold	Education	Sarasota, FL	232	1	3756/422 [67]	1346 [68]			
Energy Lab at Hawaii Preparatory Academy	[51,53]	Zone 1	2010	LEED Platinum	Education	Kamuela, HI	548.3	1	3352/2 [66]	1784 [68]			
Hawaii Gateway Energy Center	[51,54]	Zone 1	2005	LEED Platinum	Multi-use	Kailuo-Kona, HI	502.3	1	4712/0 [67]	1304 [68]			✓
Zero Energy Building BCA Academy	[53,76]	Tropic	2009 Retrofit	Green Mark Platinum	Multi-use	Singapore	4500 (2180.5 ac area)	3	6341/0 [67]	2166 [69]			
ENERPOS	[76]	Tropic	2008	High Quality Environmental Standard	Educational	Réunion, France	739 (681 ac area)	2	4097/0 [67]	1176-1505 [70]			
Ilet du Center	[76]	Tropic	2008	N/A	Office	Réunion, France	310 (11.6 ac area)	5	4097/0 [67]	1176-1505 [70]			
Zero Carbon Center	[55]	Subtropical	2012	N/A	Multi-use	Hong Kong, China	1520	3	/0 [67]	1400-3000 [71]		✓	✓
Magnify Credit Union*	[51,56]	Zone1	2010	LEED Gold	Mercantile (Enclosed and Strip Malls)	Lakeland, FL	385.6	1	3866/489 [66]	1392 [68]			
NASA Propellants Facility at Kennedy Space Center*	[51,57]	Zone1	2011	LEED Platinum	Office	Titusville, FL	886.3	1–2	3289/696 [66]	1580 [68]			
Fireside Elementary (M)*	[51]	Zone2B			Education	Phoenix, AZ	8237.2		4189/ 1125 [66]	210.6 [68]			
MEC Northeast Campus (M)*	[51]	Zone2B			Education	Phoenix, AZ	9390.7		4189/ 1125 [66]	210.6 [68]			
MEC SW Campus Phase I & II (M)*	[51]	Zone2B			Education	Buckeye, AZ	7206		3628/ 1500 [66]	191.8 [69]			
Arizona State University Student Pavilion*	[51]	Zone2B			Education	Tempe,AZ	6935.5		3655/ 1390 [66]	121.2 [69]			
Hadera Kindergarten	[58]	Mediterranean			Education	Hadera, Israel	915	1	3063/ 1846.5 [67]	1040 [69]			
Lakeline Learning Center	[59]	Zone2A			Education	Austin, TX	2180.9	1	2982/ 1508 [66]	1050 [68]			
Vallhones Prototype 1*	[60]	Zone2B	2013 (Retrofit)		Residential	Phoenix, AZ	603.9	1	4189/ 1125 [66]	210.6 [68]			

(continued on next page)

Table 3 (*continued*)

Name	Reference	Climate zone ASHRAE	Year Built	LEED Certification	Building type	Location	Size (m^2)	Stories	CDD/HDD (based on 65 °F)	Precipitation (mm)	Biomass CHP	Biomass-fired boilers	Geothermal Heat pump
Willowbrook House	[61]	Zone2A	1948		Residential	Austin, TX	159.9	1	2982/934 [66]	1050 [68]			
American Samoa EPA Office	[62]	Tropic			Office	Utulei, American Samoa	672.2	2	6087 [67]	1973 [72]			
DPR Construction Phoenix Regional Office	[63,64]	Zone2B	1964		Office	Phoenix, AZ	16500	1	4189/495 [66]	210.6 [68]			
Xingye	[65]	Hot summer and warm winter		LEED Platinum	Office	Zhuhai, Guangzhou, China	23546	17	6350/0 [67]	2067.4 [69]			
Chinese Medicine Training Building*	[183]	China Hot summer and warm winter	2015		Commercial/ multi-use	Guangzhou, Guangdong, China	50396.8	28	4085/715 [174]	1632.3 [173]	√hot water		
Guangdong Power Exchange Center*	[183]	China Hot summer and warm winter	2015		Office	Guangzhou, Guangdong, China	56215	32	4085/715 [174]	1632.3 [173]	√ hot water	✓	
Quality Inspection Center*	[183]	China Hot summer and warm winter	2014 retrofit		Office	Guangzhou, Guangdong, China	1100	3	4085/715 [174]	1632.3 [173]	√ hot water	✓	
Poly Plaza*	[183]	China Hot summer and warm winter	2012		Office	Guangzhou, Guangdong, China	25907	13	4085/715 [174]	1632.3 [173]			
Sea Union Building*	[183]	China Hot summer and warm winter	2015		Commercial/ mixed-use	Guangzhou, Guangdong, China	133326	35	4085/715 [174]	1632.3 [173]		✓	
Pearl Tower*	[183]	China Hot summer and warm winter	2016		Commercial/ mixed-use	Guangzhou, Guangdong, China	37079	19	4085/715 [174]	1632.3 [173]	√ hot water		
ITFC*	[183]	China Hot summer and warm winter	2014		Commercial/ mixed-use	Xiamen, Fuzhou, China	250847.653	30	3656/756 [174]	1300 [69]			
Technology R&D Building*	[183]	China Hot summer and warm winter	2011		Commercial/ mixed-use	Guangzhou, Guangdong, China	20105	4	4085/715 [174]	1632.3 [173]			
NUS SDE4*	personal communication	Tropics	2019	Green Mark Platinum	Education	Singapore	8514 (3500 ac area)	6	6341/0 [67]	2166 [69]		✓	

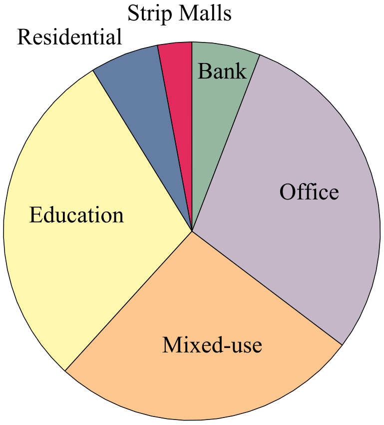

Fig. 3. Building types of the 34 net zero energy building cases.

Fig. 3 shows the different types of net zero energy building cases included in this study. Office, school and mixed-use (e.g., office and retail) are the major net zero energy building types. Most NZEBs we investigated in the U.S. and other developed regions are low-rise buildings. However, the building cases from China are mostly high-rise construction. Only two buildings are residential buildings, and the rest, 32 buildings, are commercial buildings.

4. Analysis of NZEBs in hot and humid climates

This section summarizes common design features and technology choices adopted by NEZBs in hot and humid climates, based on the cases reviewed in this study. Building technologies are reviewed and their performance is discussed and compared with ASHRAE's current standard performance. In addition to the NZEB design and technology review, we also review key operation and management methods of NZEBs adopted to achieve high performance.

4.1. Summary of design features and technologies for NZEBs in hot and humid climates

Identification of design features and technologies is essential to determining NZEB energy performance in hot and humid climate zones. We reviewed the selected 34 NZEB cases and organized their design features and technologies listed in Table 4 into five groups: architectural design and envelope; heating, ventilation and air-conditioning (HVAC); lighting; plug load equipment; and renewable energy technologies. Fig. 4 summarizes how many cases (y-axis) adopt each design feature or technology (x-axis).

Cost information of NZEB cases was also collected. Adopting energy efficiency technologies would require that the construction costs of NZEBs increase. Fig. 5 shows the cost data for 18 newly constructed NZEBs. The average construction is $4,000 (US dollars) per square meter, which is approximately double that of ordinary new construction baseline costs in the U.S. market.

4.2. Design features and building technologies

4.2.1. Architectural design and envelope

Study of the case studies revealed a few common characteristics in the architectural design features and building envelope systems of NZEBs in hot and humid climates. Eighteen cases adopted an advanced building envelope for the walls and roof. The thermal properties of the external wall and roof in these cases were further investigated, and their U values are shown in Fig. 6. We separated NZEBs built in China with NZEBs built in the U.S. and other developed countries to better illustrate country-related building envelope characteristics. For buildings in the U.S. and other developed countries, the average U value of external wall and roof for NZEBs in hot and humid climate is 0.325 W/m^2 K and 0.214 W/m^2 K, which are respectively lower than the U.S. commercial building standard ASHRAE 90.1 climate zone 1's requirements, which are 0.504 and 0273 W/m^2 K [86]. For high performance buildings in China's hot summer, warm winter climate zone, the average U value of external wall and roof for NZEBs is 1.344 W/m^2 K and 0.755 W/m^2 K, which are respectively lower than China's commercial building energy efficiency standard GB50189-2015's requirements: 1.5 W/m^2 K and 0.9 W/m^2 K. Overall, U.S. NZEBs exhibit more stringent thermal integrity than buildings in China.

There are many ways to improve NZEB envelope performance beyond current codes and standards requirements. Studies found that having better thermal integrity is effective to reduce heat transfer and heat gain from the opaque page of building envelope and thus reduce cooling loads for NZEBs in hot climates [87]. Also research has found that equipping an NZEB with a reflective roof surface to reflect solar radiation can not only effectively reduce the building's cooling load, but also help cities mitigate heat island effects in summer [88,89]. Setting up a ventilation layer between the outer envelope and indoors, by means of an attic roof, double roof, or double-skin wall, can reduce the thermal gain, with obvious effects. Advanced building envelope technologies such as phase change materials (PCM) are also used for NZEBs buildings, to damp heating transfer through the building envelope [90–92]. On-site vegetation, especially green walls and roofs, are also commonly found in NZEBs, with four cases found in hot and humid climates. Greenery combined with roofs and walls — such as roof greening, vertical greenery and hanging gardens — can ornament hard surfaces of the buildings and cool the ambient air through transpiration and photosynthesis. In the summer, green roofs can reduce heat through building roofs by about 80%, and green roofs can reduce energy consumption by 2.2%–16.7% in summer, compared to traditional roofs [93].

Twenty-two cases used advanced exterior glazing and solar shading, and 12 cases used glare control devices. From case study technology performance data, we found that NZEBs tend to use good insulation for exterior windows, with shading devices used to provide the whole fenestration system with low U value and solar heat gain coefficient. As with the opaque building envelope, we separated the U.S. and other developed country NZEBs with buildings from those in China. As shown in Fig. 7, the average U value of exterior windows for the NZEB cases in the U.S. and other developed countries was 1.824 W/m^2 K, and the average solar heat gain coefficient (SHGC) was 0.271. The glazing system's U value is better than the ASHRAE 90.1 requirement of 2.84 W/m^2 K. The SHGC value is close to, but a slightly higher than, the ASHRAE 90.1 requirement of 0.25. For high performance buildings in China, the average U value and SGHC are 3.371 W/m^2 K and 0.351, respectively, which are better than the national commercial building energy efficiency standard GB50189-2015 requirements. Overall, NZEBs in the U.S. have better fenestration system performance compared with buildings in China.

Many building cases have demonstrated using advanced building fenestration system in hot and humid climate zones. Existing studies have found that shading windows can reduce about 25% of the summer cooling load, and a total energy use reduction of approximately 20%. For a larger custom home, cooling energy is consisted of 70% of the summer cooling load using unshaded windows, while in shaded windows case, cooling energy accounted for only 45% of total energy use [94]. According to Edward Mazria [95], by precisely designing the shape of the horizontal overhang according to the sun angle calculation, the shading system can minimize the solar gain in summer while maximizing solar gain in winter. The Chinese architect Xia Changshi had proposed a series of shading design methods in the 1960s–1980s for hot and humid climate regions in China [96]. According to the sun trajectory map of Guangzhou, a city at the southern end of China situated at 23° northern latitude, Mr. Xia suggested that the projection of the overhang should be two-fifths of the height of window in the east to

Table 4
Design features and technology choices for net zero energy building cases in hot and humid climates.

Project Name	Passive Design Features												
	Window-to-wall ratio	Skylights	Solar tubes	Blinds for glare control	Optimized floor plan	Thermal zoning	Advanced envelope	Advanced glazing	Passive solar heat gain	Thermal mass	Solar shading	Natural ventilation	Site vegetation
TD Bank Branch, Ft. Lauderdale	✓			✓	✓	✓	✓	✓		✓	✓	✓	✓
PNC Net-Zero Branch	✓			✓	✓		✓	✓			✓	✓	✓
Suncoast Credit Union - Bushnell Service Center	✓			✓	✓		✓	✓				✓	
Anna Maria Historic Green Village	✓			✓	✓	✓	✓				✓	✓	
Leon County Cooperative Extension					✓		✓			✓	✓	✓	
Sarasota Audubon Nature Center	✓	✓	✓		✓			✓			✓	✓	
Energy Lab at Hawaii Preparatory Academy	✓	✓		✓	✓	✓	✓	✓			✓	✓	
Hawaii Gateway Energy Center				✓	✓		✓		✓		✓		✓
Zero Energy Building BCA Academy			✓	✓	✓		✓	✓	✓		✓	✓	
ENERPOS	✓				✓	✓	✓			✓	✓	✓	✓
Ilet du Center	✓			✓	✓	✓	✓				✓	✓	✓
Zero Carbon Center	✓	✓	✓		✓		✓	✓	✓		✓	✓	✓
Magnify Credit Union[a]					✓	✓	✓	✓			✓		✓
NASA Propellants Facility at Kennedy Space Center[a]					✓		✓			✓			✓
Hadera Kindergarten							✓	✓			✓	✓	
Lakeline Learning Center		✓					✓	✓					

(continued on next page)

Table 4 (*continued*)

Project Name	Passive Design Features												
	Window-to-wall ratio	Skylights	Solar tubes	Blinds for glare control	Optimized floor plan	Thermal zoning	Advanced envelope	Advanced glazing	Passive solar heat gain	Thermal mass	Solar shading	Natural ventilation	Site vegetation
Vallhones Prototype 1					✓		✓				✓	✓	
Willowbrook House					✓	✓	✓	✓		✓		✓	
American Samoa EPA Office				✓			✓	✓			✓		
DPR Construction's Phoenix Regional Office					✓							✓	✓
Xingye[a]		✓		✓			✓	✓			✓	✓	✓
Chinese Medicine Training Building[a]	✓					✓	✓	✓				✓	
Guangdong Power Exchange Center[a]	✓				✓	✓	✓	✓			✓	✓	
Quality Inspection Center[a]	✓			✓	✓		✓	✓			✓	✓	✓
Poly Plaza[a]	✓					✓	✓	✓			✓	✓	✓
Sea Union Building[a]	✓		✓		✓	✓	✓	✓			✓	✓	✓
Pearl Tower[a]	✓		✓		✓	✓	✓	✓			✓	✓	✓
ITFC[a]	✓					✓						✓	✓
Technology R&D Building[a]	✓				✓	✓	✓	✓				✓	
NUS SDE4[a]		✓		✓	✓	✓	✓	✓			✓	✓	✓

Project Name	Active Design Features										
	Energy efficient lighting	Efficient appliances	Efficient office equipment	Advanced lighting controls	Load management	Air enthalpy heat recovery	Hot water heat recovery	Displacement ventilation	Radiant cooling	Air source heat pump	Fans & evaporative cooling
TD Bank Branch, Ft. Lauderdale	✓	✓	✓	✓	✓	✓	✓			✓	
PNC Net-Zero Branch	✓	✓	✓	✓	✓	✓				✓	✓
Suncoast Credit Union - Bushnell Service Center	✓				✓					✓	

(*continued on next page*)

Table 4 (*continued*)

Project Name	Active Design Features										
	Energy efficient lighting	Efficient appliances	Efficient office equipment	Advanced lighting controls	Load manage-ment	Air enthalpy heat recovery	Hot water heat recovery	Displaceme-nt ventilation	Radiant cooling	Air source heat pump	Fans & evapora-tive cooling
Anna Maria Historic Green Village		✓			✓					✓	
Leon County Cooperative Extension	✓	✓	✓	✓	✓		✓			✓	
Sarasota Audubon Nature Center	✓			✓							
Energy Lab at Hawaii Preparatory Academy	✓	✓	✓	✓	✓			✓	✓		✓
Hawaii Gateway Energy Center	✓	✓	✓	✓							
Zero Energy Building BCA Academy	✓		✓	✓	✓			✓			
ENERPOS	✓		✓		✓						✓
Ilet du Center			✓	✓							✓
Zero Carbon Center	✓		✓	✓	✓	✓			✓		✓
Magnify Credit Union[a]	✓	✓	✓	✓	✓						
NASA Propellants Facility at Kennedy Space Center[a]	✓	✓	✓	✓		✓					
Hadera Kindergarten				✓							
Lakeline Learning Center	✓		✓		✓	✓					
Vallhones Prototype 1		✓				✓					
Willowbrook House		✓			✓	✓				✓	
American Samoa EPA Office				✓	✓						

(*continued on next page*)

Table 4 (*continued*)

Project Name	Active Design Features										
	Energy efficient lighting	Efficient appliances	Efficient office equipment	Advanced lighting controls	Load management	Air enthalpy heat recovery	Hot water heat recovery	Displacement ventilation	Radiant cooling	Air source heat pump	Fans & evaporative cooling
DPR Construction's Phoenix Regional Office				✓	✓						
Xingye[a]	✓										
Chinese Medicine Training Building[a]	✓					✓			✓	✓	✓
Guangdong Power Exchange Center[a]	✓			✓		✓					
Quality Inspection Center[a]	✓									✓	
Poly Plaza[a]	✓					✓					
Sea Union Building[a]	✓			✓		✓				✓	✓
Pearl Tower[a]	✓			✓		✓		✓			
ITFC[a]	✓	✓				✓					
Technology R& D Building[a]	✓	✓				✓					
NUS SDE4[a]	✓	✓		✓	✓						✓

Note.

[a] Refers to the buildings that have not yet demonstrated achievement of the zero energy goal.

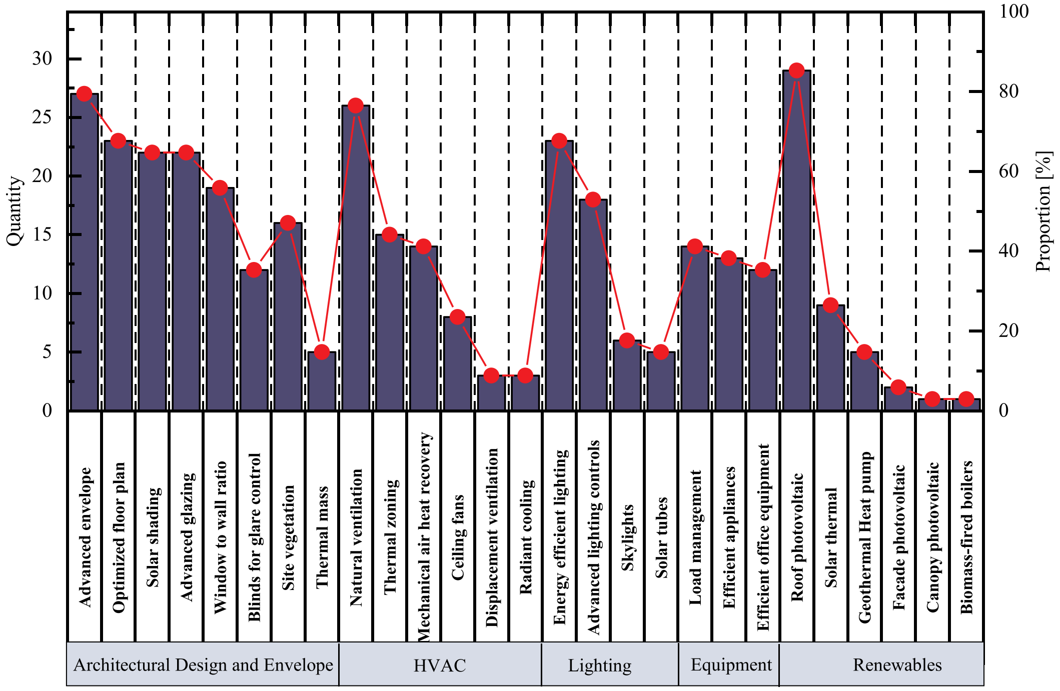

Fig. 4. Design features and building technology choices of the NZEB cases.

west horizontal direction. There is a delicate balance between shading and natural illumination in order to reduce both peak cooling load and lighting energy consumption [97]. Studies have also shown that using operable shading devices can better manage solar radiation and daylight, to minimize solar heat gain and in the summer season and also provide acceptable daylight illuminance [98,99]. Some emerging glazing technologies such as electrochromic, thermal chromic glazing, and reflective glazing are commonly used in NZEBs and can strengthen the reflection of solar radiation and reduce cooling energy consumption in hot climates [100–103].

Seventeen cases in this study optimize NZEB wall-to-window ratio (WWR). Setting up a proper WWR is beneficial for natural ventilation and daylight in transition seasons in hot and humid climate regions. However, an excessive WWR value will result in extra heat gain through exterior glazing and increase cooling energy consumption [104]. The recommended WWR value should range between 20% and 40% with low SHGC and U-factor glazing in the Zone 1 climate region in America for advanced energy design [105].

4.2.2. HVAC

The case studies indicated NZEBs are always equipped with an advanced HVAC system and energy-efficient ventilation strategies. Twenty-four cases use natural ventilation strategies to introduce free cooling to NZEBs and reduce HVAC system energy use. Many existing studies have shown that natural ventilation can reduce energy consumption and greenhouse gas emissions in buildings [106,107]. The advancement in thermal comfort theory and introduction of “adaptive comfort” criteria have also provided theoretical foundations for design and operation of natural ventilation system in NZEBs [108]. This study found that five cases adopted the use of a ceiling fan to enhance the effects of natural ventilation. Passive displacement ventilation (PDV) and high volume low speed (HVLS) ceiling fans are used typically to

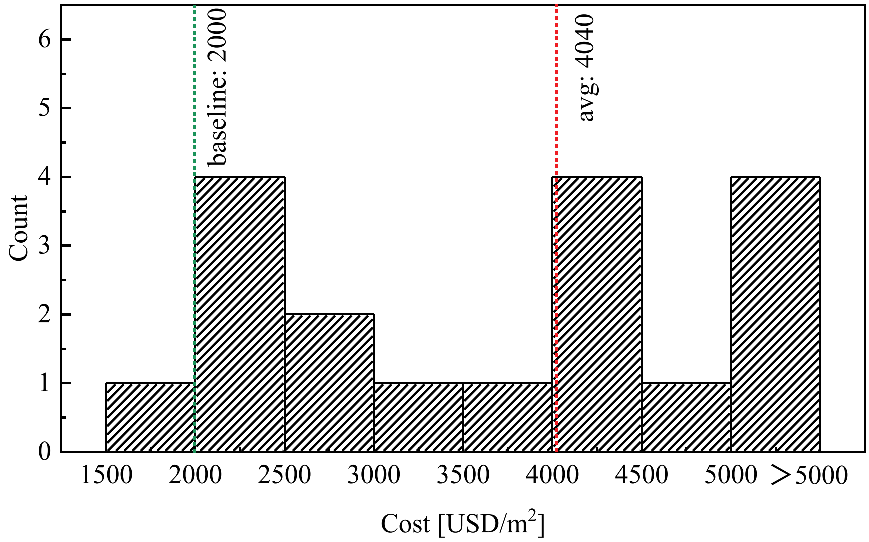

Fig. 5. NZEB net construction cost in the U.S. market.

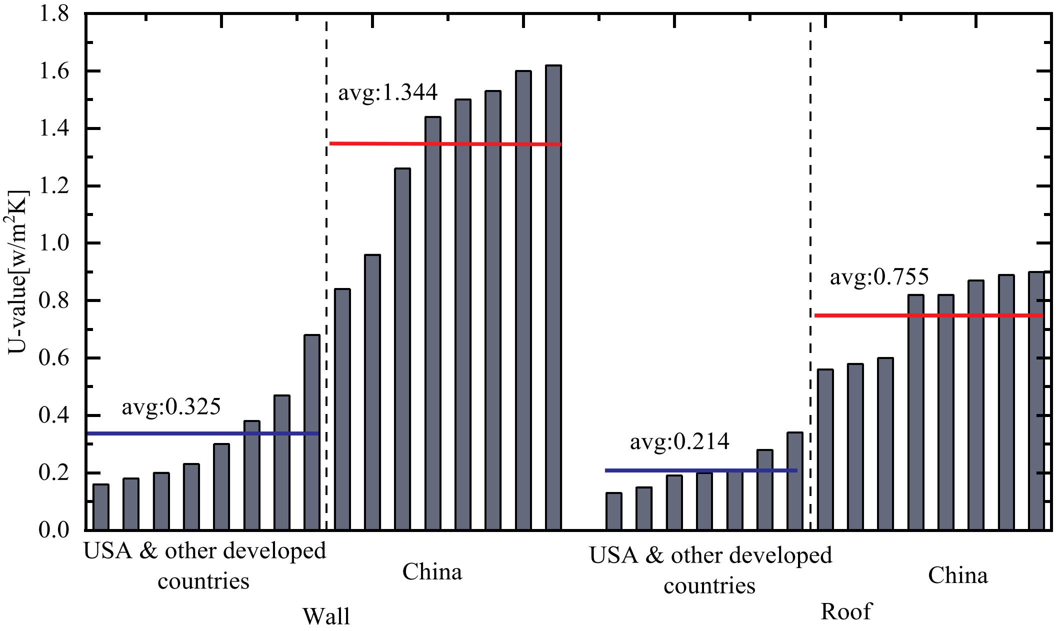

Fig. 6. U value of the external wall and roof for NZEBs in hot and humid climates.

cool large and open spaces with little furniture and few obstructions [109], such as classrooms, auditoriums, theaters, gymnasiums, lecture halls and workshop halls. Both technologies are used at the BCA Academy, a net zero energy case study building in Singapore. NZEB case studies also demonstrated the combination of a ceiling fan with a passive radiant cooling system. The combination of passive and active cooling technologies has a high potential to save energy and reduce peak power demand in hot and humid climates [110]. It also has been proven to provide better thermal comfort while saving energy at the same time [111–113].

Due to the high moisture content and latent heat in the outdoor air of hot and humid climates, getting fresh air into NZEBs during air-conditioning season is "expensive" in terms of energy use. Especially when using a radiant cooling system, dehumidification of outdoor air intake becomes very important in humid climates. The NZEB cases also show common adoption of a dedicated outdoor air system (DOAS) to treat outdoor air. Dehumidification can be achieved with a high efficiency DOAS with energy recovery wheels and deep multi-row cooling coils [114]. DOAS in NZEBs are often operated using a temperature and humidity independent control (THIC) method [115,116]. On the cooling equipment system side, advanced ground sourced heat pumps (GSHP) are widely adopted in NZEBs. The most appealing case is the Hawaii Gateway Energy Center, which not only uses GSHP to produced chilled water, but also uses deep cold 7 °C seawater to cool the outdoor air intake to 22 °C, with very small seawater pumping energy consumption [117]. According to Saeid Khalil [118], seawater air-conditioning technology has great potential as a kind of clean renewable energy in hot climate regions, especially at tropical islands.

4.2.3. Lighting

Lighting energy efficient strategies in NZEBs are often observed to maximize the use of daylight through passive daylighting technologies and to improve artificial lighting devices and control system efficiency. Based on our case studies, daylighting in NZEBs is achieved through daylight from facades and use of skylights and solar tubes. Daylight from facades requires that the fenestration system has high visible light

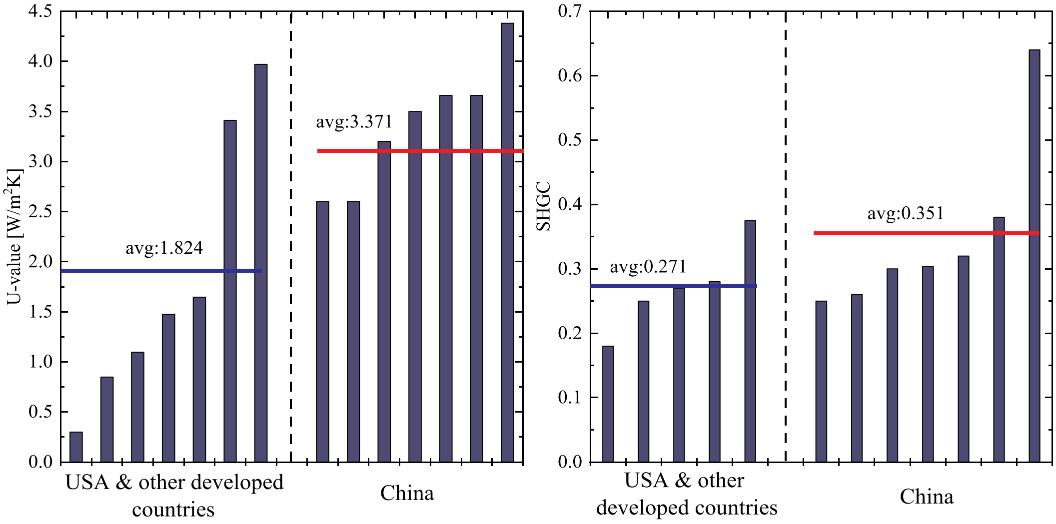

Fig. 7. U value and SHGC of fenestration system for NZEBs in hot and humid climates.

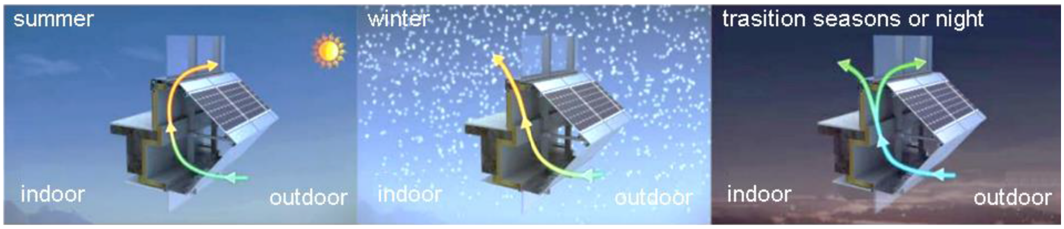

Fig. 8. BIPV in Xingye office building in Zhuhai city China (Source: Xinye Solar, personal communication).

transmittance. The *Advanced Energy Design Guide for Small to Medium Office Buildings*, published by ASHRAE, suggests that the ratio of visible transmittance (VT) to SHGC should be at least 1.10 in hot and humid climates [119]. However, introducing daylight can also risk increasing solar heat gain. Thus, the choice of glass type and layer is critical to achieving the balance between natural daylight and reducing heat gain from the solar radiation in NZEB design [120]. Moreover, utilizing daylight from facades is often integrated with blinds and glaring control, which is introduced in the building envelope section. The use of vertical daylight through solar tubes and skylights is also commonly found for low-rise NZEBs. Making use of daylight requires the design of NZEBs to integrate various passive measures to reduce lighting load density, and hence reduce the necessity of artificial lighting devices [121].

Active lighting strategies in hot and humid climates have great energy saving potential. In-depth research by Sun et al. [27] on the NZEB renovation project in Singapore found that energy-efficient lighting and high performance air-conditioning systems are the most energy-efficient retrofits in the hot and humid climates of the tropics. The study also pointed out that lighting retrofits using efficient light-emitting diode (LED) lighting are cost-effective and have a short payback period. This study found that 23 cases use LED lights to improve artificial lighting system efficiency. The advances in lighting technology, such as occupant-centered lighting control [122,123], LEDs [124,125], and organic light-emitting diodes (OLEDs) [126] have led to widespread energy-efficient lighting designs and are going beyond energy savings by improving occupants' well-being and mental health at the same time [127,128]. Lighting controls are essential to effectively integrate passive daylight utilization with artificial lighting devices [129]. A proper design and operation of lighting control system together with shading devices can also help improve NZEB energy efficiency and achieve better visual comfort [130]. As LED lighting performance has increased in the past decade, and the price has dropped by 90% [131], there is a great potential for developing countries in tropic climates to adopt high performance lighting in their NZEBs.

4.2.4. Plug load and equipment management

Plug load energy use is relatively constant under all climatic conditions, and less impacted by the other building systems mentioned previously [132]. Plug loads can consume one-third of a building's energy consumption [133] and can therefore become an important contributor to building energy consumption in low-energy buildings like NZEBs. Many countries' building energy codes and standards do not have prescriptive measures on plug load energy efficiency, which makes it difficult to implement energy conservation measures for plug loads in NZEBs [134].

The collected NZEB case studies in this paper found that many cases adopted the two principles from advanced energy design guides published by ASHRAE [135] to reduce plug load energy use by selecting: (1) equipment with lower power demands, and (2) equipment usage controls [119]. The key to the first method is the choice of equipment, such as using more laptops instead of desktop computers, and purchasing certified energy-saving equipment such as ENERGY STAR-labeled equipment. For example, a study of small- and medium-sized offices [119] simulated a 5,000 m^2 office building and showed that plug load density can be reduced by 0.68 W W/m^2 immediately by changing the usage of half-to-half desktop/laptop computers into 25% desktops and 75% laptops with ENERGY STAR labels. The second method focuses on smart controls such as occupancy sensors, time switches, and computer power management, as well as controls that allow a user to control usage according to their own needs. The Internet of Things (IoT), smart and networked devices, and cultivated user behaviors can also represent important energy efficiency opportunities. Energy-saving user behaviors can be cultivated through personnel management education, training and incentive-driven policies in environmentally friendly family or corporate cultures, and to form good usage habits. Almost all electronic devices today have phantom load losses, which is affected significantly by user behaviors, and they can consume up to 5% of plug loads [119].

4.3. Renewable energy system

Utilizing renewable energy is a key step for buildings to achieve net zero. Solar photovoltaics are the most common renewable energy technologies adopted by NZEBs cases, with 30 cases found in this research. For low-rise NZEBs, rooftop PV installation is commonly found. Roof space on high-rise buildings is limited, so ways have been developed to install PV on NZEB facades. Fig. 8 shows the Zhuhai Xingye NZEB's building integrated PV (BIPV) design. As a high-rise NZEB, the PV is integrated at the buildings' south facade. A natural ventilation pathway was designed to circulate air at the back of the PV panel in order to reduce the panel's temperature and increase its efficiency. A natural ventilation opening is provided at the back of the PV panel. During the summer season, the natural ventilation opening is closed, and the building is operated in air-conditioning mode. During wintertime, the natural ventilation window is open, and the outdoor air can flow through the back of the PV, take the heat from the PV panel, and bring it to the building. This design intelligently integrated the renewable energy system with the building envelope and natural ventilation, thus greatly improving the NZEBs performance.

Utilizing wind energy is not very common in buildings, as relative low wind speed at the ground level. However, there are cases that demonstrate novel ways to utilize wind energy in high-rise buildings. Fig. 9 shows a high performance building project in Guangzhou, China. Four large vertical wind turbines installed in the middle and top sections of this high-rise building generate 288,000 kWh of electricity annually — even more than that generated by its solar panels [136].

To provide thermal energy for NZEBs, a renewable alternative to fossil-fuel-based technologies for hot water supply is to use solar-thermal systems [137,138]. In hot climate regions such as Australia, for example, a best-design solar thermal system can supply about 60%–70% of the total annual hot water demand to heat water for domestic use, such as baths and cooking [139,140]. Generally, the combination of solar electric and a heat pump in a single system is a promising water heating system technology that can significantly enhance a systems' performance with lower cost [141,142]. Solar hot water is also a cost-effective technology when combined with local and central government financial incentives [61].

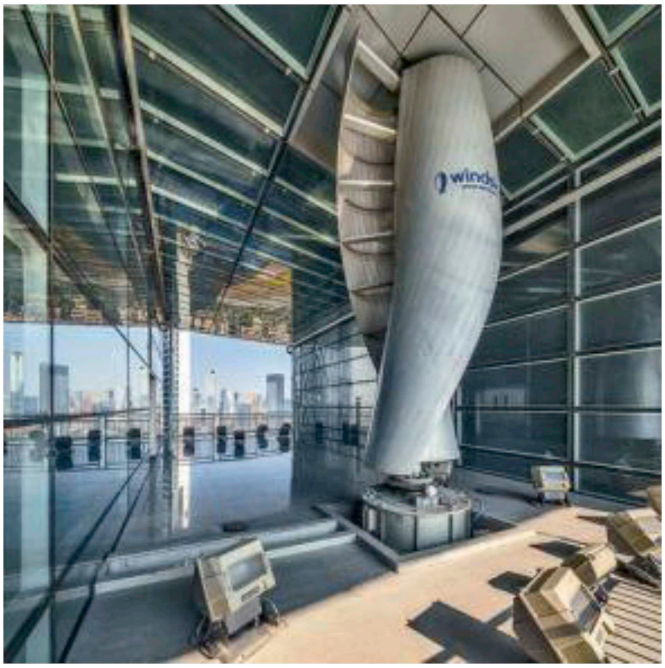

Fig. 9. A wind turbine installed in the Pearl River Tower building (Source: SOM, Pearl River Tower, Jan 2014. www.SOM.com).

4.4. Operation and maintenance

NZEBs require buildings to purchase electricity from the power grid when its local renewable energy generation is not sufficient and sell extra electricity back to the grid when generation is more than NZEBs energy demand. Therefore, a major challenge in power quality and grid operations is the integration of renewable energy generation [143]. Recently, much smart grid research and development [144] has increased the understanding of the interaction between renewable energy technologies and the distribution grids to minimize the cost of integrating renewable energy to the distribution grids [145,146]. The stand-alone NZEBs, which are not connected to the grid, have to balance the energy demand through renewable energy systems onsite to support the building's daily operation. For this kind of NZEB, the challenges of daily fluctuations in renewable energy source and instability in energy production are greater. In hot and humid areas, some tropical islands and less developed villages have no access to electricity from the grid [147,148], and this type of NZEB can be used there. During operation, it is especially important to optimize renewable energy controls so the stand-alone NZEB can function all the time.

Operation and maintenance can make sure NZEB technologies and design features can operate as originally designed to satisfy occupants' needs. Smart buildings provide flexibility through energy control, storage and demand response [149] to achieve zero-energy goals. By 2040, smart controls are predicted to reduce global building energy consumption by 10% [150]. The analysis of the role of digitization in buildings conducted by IEA found that smart controls and connected equipment could save an accumulated 230 EJ (EJ) of energy by 2040, reducing global building energy consumption by up to 10% while improving thermal comfort for occupants. Increasing user control over cooling to optimize heating and cooling systems is often overlooked [2]. Previous research has shown that user-led innovation that deepens user control of building systems and the indoor environment can improve occupant comfort and satisfaction [151,152]. Through building control technologies, the savings can be between 15% and 50% [153]. Therefore, better control can considerably impact user comfort and efficient operation of the cooling system, including pumps and ventilation [2]. Training building occupants and operators, and monitoring buildings, are two major strategies to achieve building energy efficiency [133]. A controllable thermostat can save an additional 10%–25%, depending on user behaviors and architectural features, compared to an automatic thermostat [154,155]. Such investments are usually not capital-intensive and have a short payback period, which is suitable for developing countries.

The operation and management of cooling systems is critical for NZEB performance. The user's requirements for thermal comfort will also have impacts on energy consumption, as thermal comfort parameters have strong impacts on air-conditioning demand [174]. In hot and humid areas, the room set points of air-conditioning, the internal heat source, and the maximum allowable room temperature affect the cooling demand significantly in the built environment [78,131,156]. When the summer set temperature was reduced by 1 °C in one office building studied in Sydney, Australia, energy consumed for cooling decreased by 6% [157]. The peak demand for residential buildings in Las Vegas decreases by 69% when the summer set temperature drops from 23.9 °C to 26.9 °C [158].

4.5. Integrated design and performance optimization

Previous research and real-world cases have demonstrated that by integrating energy efficiency measures and renewable energy systems, the goal of a sustainable NZEB can be achieved and maintained [159,160]. High initial investment and a long investment payback period have always been major obstacles to NZEB development, especially for economically developing and underdeveloped areas in hot and humid regions. The integration of different energy-saving and renewable energy technologies at the lowest cost should be the main principle considered for achieving NZEB goals in these areas [25].

For NZEBs in hot and humid climates, the integrated design of active and passive strategies become extremely important. With the economic development of hot and humid regions, the integration of natural ventilation with an air-conditioning system in an NZEB will become mainstream. As discussed, the balance of two systems is the key to achieving the energy-saving goal. Lu et al. [161] conducted the sensitivity analysis on an NZEB in Hong Kong, and the result shows that the wind velocity has a significant impact on annual energy balance, cost effectiveness, and carbon dioxide emissions. It is also the key factor of the passive design of natural ventilation. The second is the hybrid renewable energy system integration design, based on stability and overall zero energy performance. Many Hong Kong scholars have conducted studies on hybrid energy systems under uncertainties to improve overall NZEB performance in Hong Kong, a city in a hot and humid region. Zhang et al. [162] proposed a multi-criterion renewable energy system design optimization method for NZEBs under uncertainties and indicated that careful renewable energy system sizing was necessary to achieve optimal overall performance. Sun et al. [163] found that sizing of the air-conditioning system and renewable system are critical to avoiding poor building performance. Lu et al. [164] emphasized uncertainties in renewables of NZEBs and proposed a robust design method for renewable energy system sizing. The third, known as the cost-optimal design, is an optimized design based on cost considerations. Based on the sensitivity analysis of design parameters for the NZEB system by Sun [165], the most sensitive parameter for the cost of the initial investment is the temperature set point of indoor environments, system coefficient of performance (COP) and internal gain intensity. Therefore, in the search for NZEB solutions, multi-objective optimization [166,167] is needed instead of a single-objective approach, to deal with various conflicts such as different combinations of renewable energy, improved energy-saving efficiency versus incremental cost, and how to improve thermal comfort with passive design strategies. Among the various optimization methods used to simulate building performance, genetic algorithm (GA) for multi-objective optimization is the most commonly used strategy for performance analysis [168].

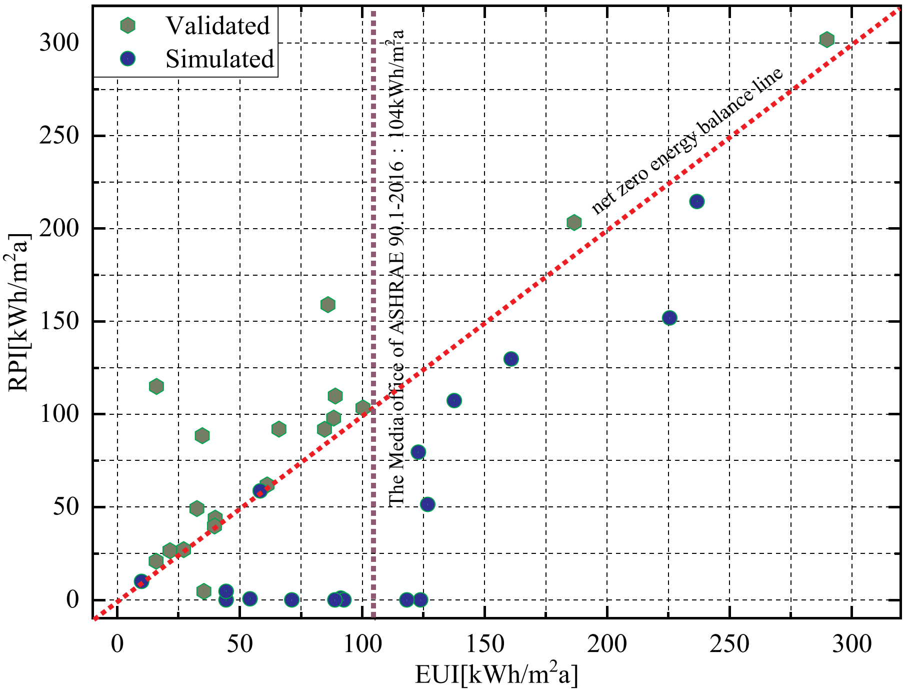

Fig. 10. Energy generation/consumption balance of selected NZEB cases.

5. NZEB energy performance analysis

This study tracks building energy performance in all 34 cases. The energy use and renewable energy generation data of the case study buildings are collected annually. Note that to calculate renewable energy generation in these cases and make them comparable to each other, this study used site renewable energy generation in this analysis and ignored purchased remote renewable energy generation. Since case study NZEBs in hot and humid climates use electricity as the main energy form, this analysis uses site energy to calculate the relationship between energy consumption and renewable energy generation. In all reviewed 25 cases, 17 NZEBs have been validated to achieve or designed to achieve net zero energy or "net positive energy" (i.e., generating more energy onsite than is consumed). Eight buildings did not achieve the net zero energy target and still use more energy than their local renewable energy generation.

5.1. NZEB overall energy performance

Fig. 10 shows all the case study buildings' energy use intensity (EUI) and renewable energy production intensity (REPI), both in kilowatt-hours per square meters of building floor space on an annual basis. If a building reaches its net zero energy target, its EUI and REPI point should be on the 45° dashed line, meaning its annual energy consumption is the same as its local renewable energy generation. Should a building generate more renewable energy on site than it consumes, its energy performance will be above the 45° dash line. Similarly, if a building uses more energy than it generates locally, its energy performance will be below the 45° dashed line. Note that most of the buildings have EUI values around 100 kWh/m^2. To further assess the energy efficiency performance of NZEs, we used the energy use intensity of the ASHRAE 90.1–2016 standard's climate zone 1, middle-size office building, as a baseline [169]. There are still some NZEB energy use intensities higher than the ASHRAE 90.1–2016 standard's reference office building's energy performance, meaning that not all NZEBs are high energy performance buildings. That is, a building can still be net zero without stringent energy efficiency measures if it has ample local renewable energy resources on site.

We further investigated why some NZEBs still use more energy than the ASHRAE 90.1 standard's requirements. The review found that some of these buildings are commercial banks, with large internal plug loads such as servers and computers, and that they have stringent requirements for artificial lighting [177]. The large internal heat gain from computers and servers also requires large energy consumption for cooling. Because of building functional requirements, the passive design features such as natural ventilation and daylighting are difficult to fully utilize in these NZEBs, which results in high energy consumption.

To further understand NZEB energy performance, the study compared renewable energy technology installation capacity with building energy use and renewable energy generation intensity. As most of the case study buildings use on-site solar PV as the renewable energy technology, this paper uses solar PV installation intensity as a parameter to assess NEZB performance. The PV installation intensity is defined as the ratio of total solar PV installation capacity (kW) to the building's total floor space (m^2), with a unit of W/m^2. A single-floor building, with its entire rooftop installed with PV[2] and no other PV installation on its facade or adjacent facilities, has a PV installation intensity of about 119 W/m^2. A smaller PV-to-floor-space ratio means that an NZEB may have less roof or façade area to install the PV. Fig. 11 shows the relationship between PV installation intensity and the ratio of REPI to EUI for NZEB cases.

Note that when the REPI/EUI ratio is less than 1, it means a building consumes more energy than it locally generates, and thus does not achieve the net zero target. A building with the REPI/EUI equal to or bigger than 1 achieves net zero or even becomes net positive. However, this study does not just use net zero as the single criteria to evaluate NZEB performance. To further analyze performance of the case study buildings, we used the calculated 119 W/m^2 baseline discussed above to evaluate whether an NEZB mainly utilizes its local on-site PV (lower than the baseline value) or has extra resources for renewable energy generation at its adjacent facilities (higher than the baseline value). The research is especially interested in buildings that do not utilize adjacent

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[2] We assume that: PV are installed at the roof with a 20° tilt angle facing south, about 70% of an NZEB's rooftop area can be used for PV installation, and the rest (30%) of the area is used for maintenance and walking space.

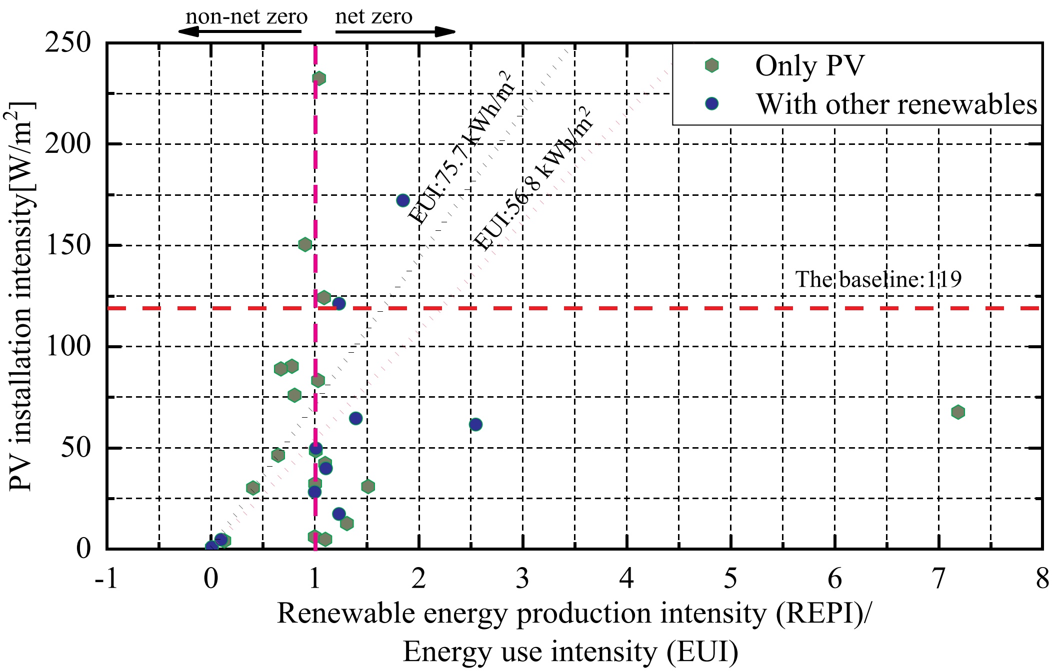

Fig. 11. The relationship between PV installation intensity and REPI to EUI ratio (REPI: renewable energy production intensity kWh/m^2 floor space; EUI: energy use intensity kWh/m^2 floor space).

on-site renewable generation facilities, or cases below the baseline value. To study the relationship between PV installation intensity and REPI/EUI ratio, we used the EUI value 56.8 kWh/m^2 (18 thousand btu per square foot, kbtu/ft^2) defined by NBI's zero energy verified projects, as our case study energy performance criteria [170,171]. Using that criteria, a line is shown in Fig. 11, with PERI calculated by using Hong Kong weather conditions. For buildings, even though not achieving net zero with a REPI/EUI ratio less than 1, if their energy performance is located at the right part of the EUI = 56.8 kWh/m^2 line, we may still want to call these buildings “net zero energy ready buildings.” The reason is that these buildings may have limited renewable energy resources to install PV, but their energy efficiency measures are well implemented and therefore the buildings have low EUI. Should more renewable energy resources be identified in the future, these buildings would still be able to achieve net zero energy performance. Similarly, for building performance located at the left of the EUI = 56.8 kWh/m^2 line, even though some of them achieve net zero energy requirements with REPI/EUI equal to or bigger than 1, their EUI is still high, and energy efficiency measures may still have the potential to improve and further reduce NZEB energy consumption. NBI also gives another definition of emerging NZEBs, where EUI = 75.7 kWh/m^2 (24 kbtu/ft^2). Another EUI line can be also drawn to assess NZEB performance based on this EUI value. Note that the PV installation intensity value and EUI values demonstrated in this paper are just ways to evaluate NZEB performance. When applying to specific countries or regions, and using the different ways to utilize renewable energy technologies, slightly different values could be used for NZEB performance analysis.

5.2. Detailed energy performance analysis for the case study buildings

This research examines energy performance of three NZEB case studies; two in the U.S. and one in China (Fig. 12). The U.S. cases are a commercial office building located in Arizona (U.S. bldg. #1) and a mixed-use retail and office building (U.S. bldg. #2) located in Florida. The Chinese building, Xingye HQ office building, is located at Zhuhai, Guangdong province. We compared these buildings' energy use and renewable energy generation data on an annual, monthly and typical performance day basis, and summarized the NZEBs’ detailed energy performance.

Fig. 13 shows the annual energy performance for two buildings: Xingye and U.S. building #1. We found that cooling related HVAC energy use takes a big portion of an NZEB's total energy use in hot and humid climates, with Xingye using 34% and U.S. bldg. #1 using 50%. Plug load and equipment use accounts for about 30% of the NZEBs' total energy use, and lighting accounts for about 10%. The Xingye building, as a high-rise office building, has limited on-site renewable resources and did not achieve its NZEB target. However, it demonstrated excellent energy efficiency performance with a total EUI of 35 kWh/m^2. If its data center energy use is deduced, its EUI could be further reduced to 25 kWh/m^2. Note that its EUI is much lower than NBI's 57.6 kWh/m^2 target. This is due mainly to its integration of passive measures and technologies such as natural ventilation and daylighting, reviewed in

Fig. 12. Three NZEB cases: U.S. bldg. 1 (left, NBI 2018), U.S. bldg. 2 (middle, NBI 2018), Xingye building (right).

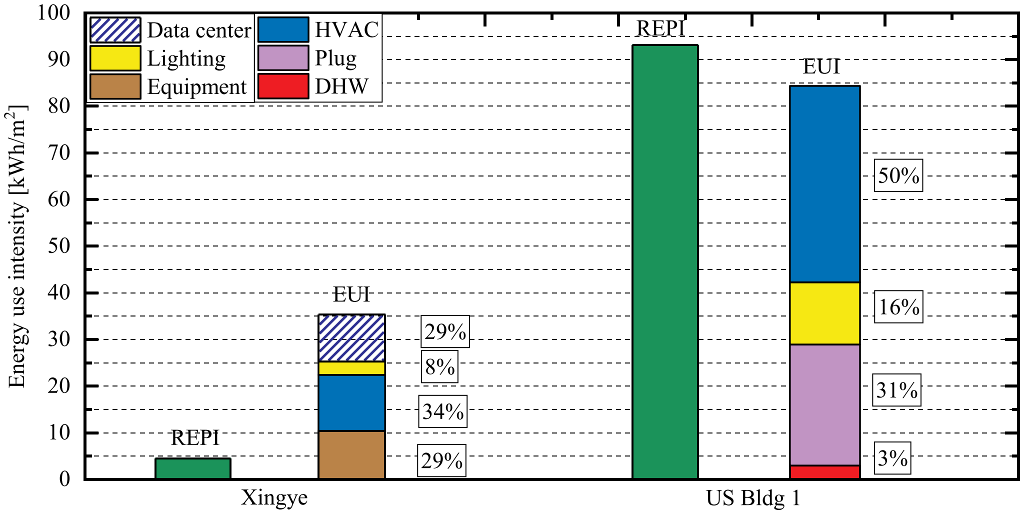

Fig. 13. Annual energy performance comparison between Xingye and U.S. building #1.

previous sections.

In terms of monthly energy use, the energy consumption and renewable energy generation of three case study buildings are shown in Fig. 14. Their net energy use was also calculated and shown in the dashed lines. The study found that all cases use more energy during the summer season because of the large cooling and ventilation energy demand. Even though all the cases are located in the Northern hemisphere, the NZEBs' solar PV electricity generation does not necessarily peak in the summertime. In the two U.S. cases, PV energy generation peaks in April and May. The study also found that the two U.S. NZEBs achieved net positive energy during winter and shoulder seasons, and that buildings often need to purchase electricity from the power grid in the summer.

Fig. 15 shows a further in-depth look of Xingye building's monthly energy data. The data show that the building is tightly managed to operate its HVAC system mainly during the summer season for a bit more than five months, from May to September. In the rest of the months, HVAC energy use is very small. Lighting energy use in Xingye is less than 1 kWh/m^2 per month and very constant, meaning that the building constantly utilizes daylight all year long and has a highly efficient artificial lighting system.

Daily energy use in the Xingye building was also collected, and is shown in Fig. 16. Across different seasons' workdays, we observe that the building is strictly managed to turn on the equipment that uses the major portion of its energy at 8 a.m. The base load of the building is around the 2 Wh/m^2, while in cooling season, the daily peak load is around 13 Wh/m^2. The peak to off-peak ratio is 7.12. In the non-cooling days, the peak load is relative lower, with the peak to off-peak ratio between 2 and 3. The base load management in this NZEB is well achieved — another successful experience we can learn from to improve NZEB performance.

6. Discussion and conclusion

This section summarizes NZEB energy performance. It concludes with the policies drivers and recommendations for NZEB development

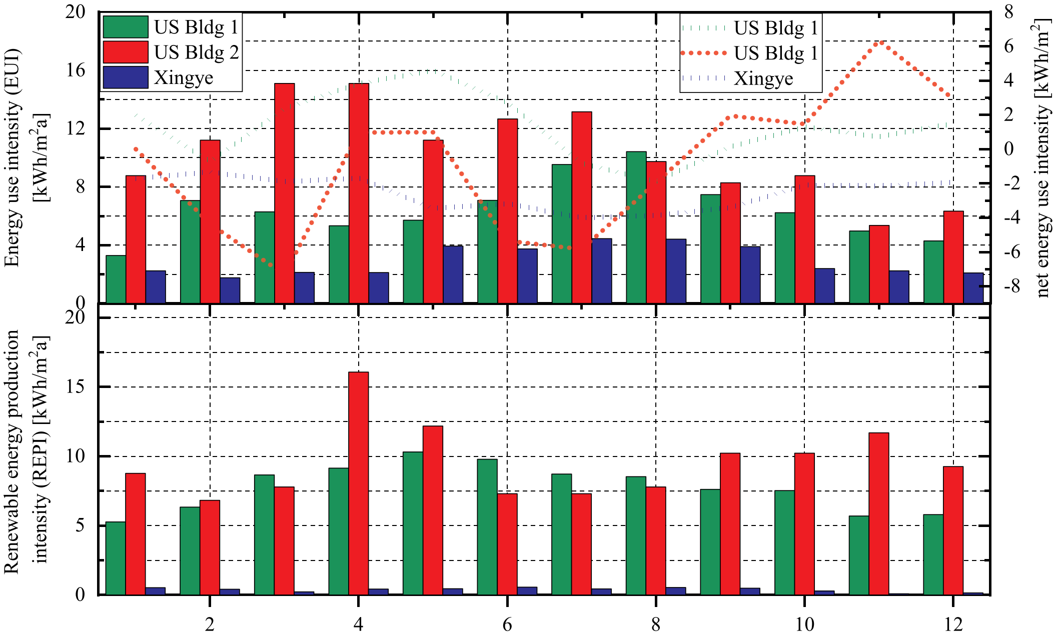

Fig. 14. Monthly energy data of NZEBs.

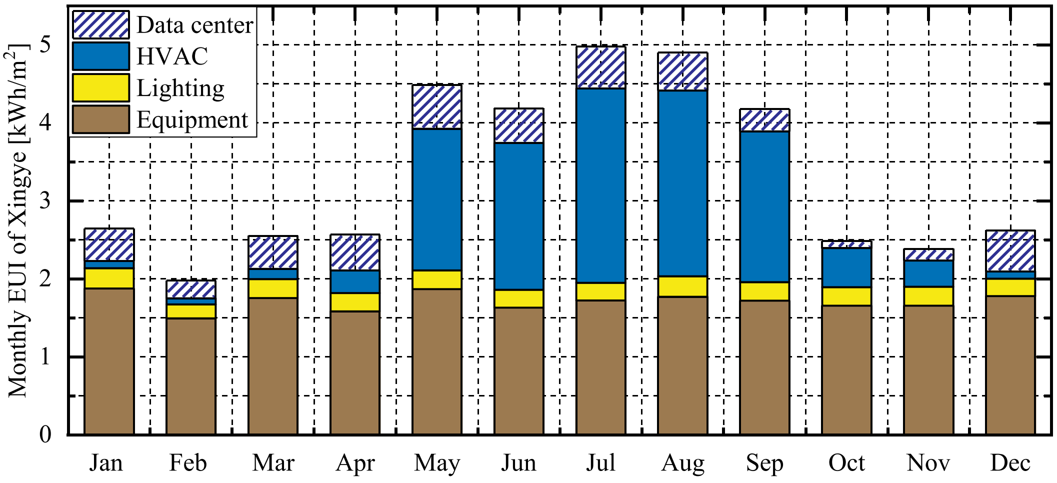

Fig. 15. Xingye building monthly energy use profile.

in hot and humid climate regions. The limitations of this study are also provided.

6.1. NZEB energy performance

1) NZEBs tend to employ multiple energy-efficient technologies, but not all NZEB cases are energy efficient.

The review showed NZEBs tend to adopt advanced energy efficiency design and technologies. On average, each case study adopted 12 passive design features and technologies. Analysis in this paper also found that NZEBs tend to adopt high performance building technologies. For building envelope, for example, the case analysis found that NZEBs in hot climates tend to have measures more stringent than their country's energy standard requirements. However, high performance technologies alone cannot guarantee high energy performance. NZEBs also need to employ effective operation to ensure actual operation performance meets goals. Building operation needs to integrate the passive strategies implemented for NZEB in hot and humid climates together with the active system. The operation rule should follow the principle “passive first, active optimized” to design and use passive measures first, and then optimize active technology performance. The case studies demonstrated that using natural ventilation and daylighting passive technologies can significantly reduce NZEB energy use.

Through the analysis, we found some NZEBs exhibit high EUI: more than 200 kWh/m^2. Only with ample local renewable energy resources can these buildings achieve the NZE target. A true NZEB should be an energy efficient building first, then properly integrate renewable energy. As demonstrated in this study, each country or region can develop its criteria to assess NZEB performance with energy efficiency as a first priority. An energy use intensity-based criteria should be established for all NZEBs to evaluate their energy efficiency performance. The criteria the New Building Institute in the U.S. developed — the “net zero energy ready” criteria with an EUI equal to or less than 56.8 kWh/m^2 — is a good reference to evaluate NZEBs performance.

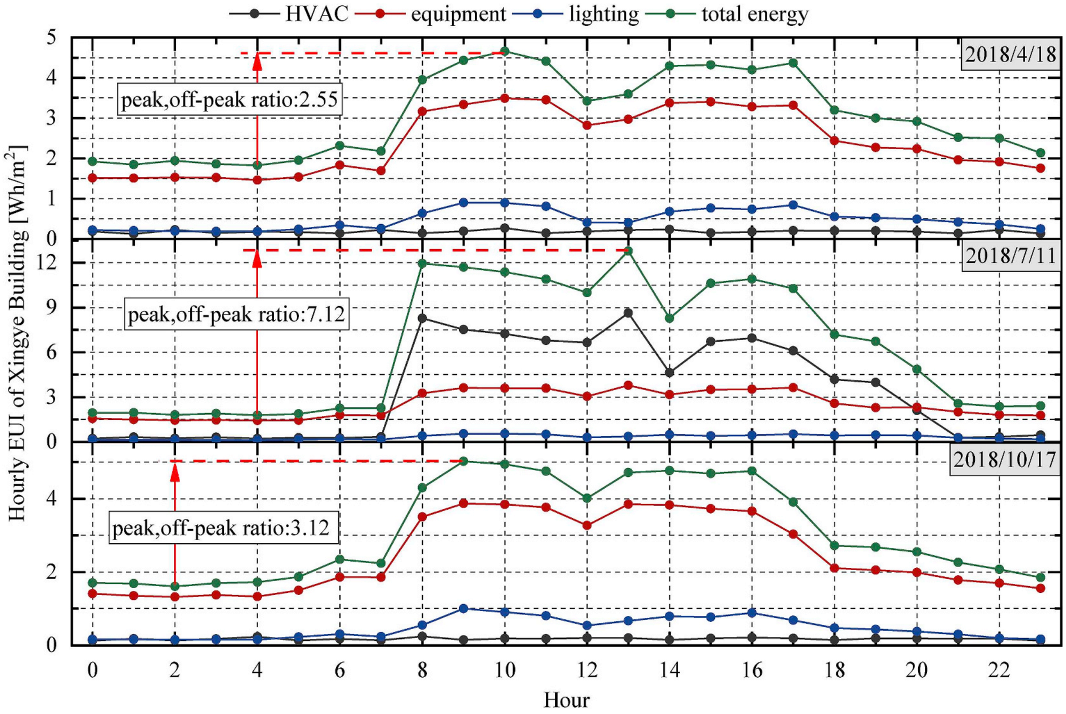

Fig. 16. Daily energy use profile in Xingye in representative workdays.

2) Natural ventilation and other passive technologies can effectively help NZEBs reduce their cooling energy use. The Xingye building case demonstrated that natural ventilation could reduce the building's cooling energy from 2.5 kWh/m^2 to less than 0.5 kWh/m^2 per month — an 80% cooling energy reduction in the shoulder seasons compared with the summer season. With daylighting, the Xingye building demonstrated that monthly lighting energy intensity can be controlled less than 0.5 kWh/m^2.
3) PV are the most common renewable energy technologies. To achieve the NZEB targets and increase renewable energy penetration in high-rise buildings, BIPV design is important. As demonstrated by case studies, BIPV can be integrated well with the building envelope system and coupled with natural ventilation to improve the PV system's performance, and provide good indoor thermal comfort. Integrating PV with a building's facade is becoming more and more common, especially in emerging economies like China where multistory high-rise buildings are commonly built. As the Xingye building demonstrated, an effective way to integrate BIPV with natural ventilation can successfully bring PV panel-heated outdoor air into the building during the winter and shoulder seasons.
4) To achieve high energy performance during operation, effective operation management and engagement with occupants are also very important. To achieve a high peak to off-peak energy use ratio — for example, 7 during the cooling season, as demonstrated in the Xingye building case — building managers must work with the NZEB energy management system to engage occupants and effectively control the buildings' base load during off-work hours. To achieve low energy performance in NZEBs, it is essential to train occupants and create occupant awareness to use passive measures.

6.2. Policy recommendations

1) The adoption of advanced technologies in NZEBs are strongly influenced by their countries' building energy codes and standards. During the case analysis on NZEB envelope performance, we found a strong correlation of NZEB envelope performance with China and U.S. building energy efficiency standards. The U.S. NZEBs show that its envelope U values are very close and slightly better than ASHRAE90.1 standard requirement. Similarly, Chinese buildings have also demonstrated building envelope improvement over China's current commercial building energy efficiency standard. Thus, setting up stringent building codes and standards would help advanced building envelope technology adoption in NZEBs, and facilitate the social scale adoption of NZEBs. For example, California has developed its state-level net zero building pathway, which requires all new residential buildings to be net zero by 2020, and all new commercial buildings to be net zero by 2030. Its Title 24 building code is revised continuously to reach the targets. The continuous upgrades of the building code towards net the zero target is a key reason that NZEBs are increasingly adopted in California. Moreover, as discussed previously, to ensure NZEB actual operation energy efficiency, codes and standards should also move from a current emphasis on building technology prescriptive measures to actual building outcome-based energy performance.
2) This research found that barriers still hinder NZEB adoption. A key barrier is their high upfront cost. To enhance the wide adoption of NZEBs in the market, especially in developing countries, policies and incentives are needed to help building owners overcome the high incremental cost. It is also important to document the savings of NZEBs; not just the energy benefits, but also non-energy benefits such as indoor air quality, increased occupant productivity, and so on. Educating building owners about these benefits enhances their awareness and can foster future NZEB development. Other barriers, such as the lack of personnel capacity on NZEB design, construction, operation and management, need to be overcome to increase NZEB development.
3) Finally, this review found that some countries have developed NZEB standards and policies to support NZEB development. Some countries only have NZEB demonstration cases, but no clear policies on national or local levels. Admittedly, case studies effectively present examples to lead NZEB development; however, to ensure wider adoption of NZEBs in hot and humid climate regions, policies such as standards, incentives and capacity building are important ways to further cultivate the market on a social scale. National and local governments can summarize the successful experiences of NZEB demonstration cases in hot and humid climate regions, and ensure such experiences can be applied as supporting policies to foster NZEB development.

6.3. Limitations

This paper still has some limitations, and future research is needed. As net zero energy buildings are still a new concept in many countries, only 34 cases are found in hot and humid climate regions. Moreover, not every case analyzed in this study has comprehensive design and performance data available. Thus, there is a great need to document NZEB best practices in a future study, and enhance data transparency. Comprehensive documentation of design, cost and performance data would make a case study of a successful experience more convincing when disseminated to an audience. Operational conditions should be documented side-by-side with building operation energy data to demonstrate the effectiveness of advanced design and technology performance in the operation stage. Energy consumption data are needed in different time intervals, such as: yearly, monthly and typical day hourly data. For emerging economies in hot and humid climates, documenting best practices would be very helpful to demonstrate the effectiveness of NZEBs and thus reduce knowledge barriers among stakeholders. With more and more NZEBs built and data documented in the future, in-depth analysis with larger sample sizes can be conducted.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rser.2019.109303.

References

[1] EIA. International Energy Outlook 2017 Overview. U.S. Energy Information Administration IEO2017 (2017) vol. 143. 2017www.eia.gov/ieo%0Ahttps://

www.eia.gov/outlooks/ieo/pdf/0484(2017).pdf.
[2] IEA. Energy Technology Perspectives 2017. www.Iea.Org: 443. 2017http://www.oecd-ilibrary.org/energy/energy-technology-perspectives-2017_energy_tech-2017-en.
[3] EIA. How much energy is consumed in U.S. residential and commercial buildings? Retrieved https://www.eia.gov/tools/faqs/faq.php?id = 86&t = 1, Accessed date: 1 October 2018.
[4] Ionescu C, Baracu T, Vlad GE, et al. The historical evolution of the energy efficient buildings. Renew Sustain Energy Rev 2015;49:243–53.
[5] Passipedia. Anmerkungen zur Geschichte Retrieved https://passipedia.de/grundlagen/anmerkungen_zur_geschichte, Accessed date: 1 October 2018.
[6] Torben V. Dimensioning of the solar heating system in the zero energy house in Denmark. Sol Energy 1977;19:195–9.
[7] EPBD. Directive 2010/31/EU of the European Parliament and of the Council of 19 May. 2010.
[8] IEA. Brussels-Capital Region. Apply PEB requirements comparable to the passive concept for all new constructions by 2015 Retrieved https://www.iea.org/policiesandmeasures/pams/belgium/name-125493-en.php; 2015, Accessed date: 1 October 2018.
[9] Ministry of Environment. Energy and the sea. Energy transition for green growth Act. http://www2.developpement-durable.gouv.fr/IMG/pdf/16172-GB_loi-TE-les-actions_DEF_light.pdf; 2015.
[10] Centre for Energy Efficiency. Denmark's national Energy Efficiency action plan (NEEAP). https://ec.europa.eu/energy/sites/ener/files/dk_neeap_2017_en.pdf; 2017.
[11] Crawley D, Pless S, Torcellini P. Getting to net zero. ASHRAE J 2009;51(9):18–25.
[12] DOE. Building Technologies program planning summary. https://www.energy.gov/sites/prod/files/2013/11/f5/btp_planning.pdf; 2008.
[13] California Public Utilities Commission. Zero net Energy action plan Retrieved, http://www.cpuc.ca.gov/ZNE/; 2015, Accessed date: 1 October 2018.
[14] Energy Step Code Council BC Energy Step Code. 2010 on the energy performance of buildings (recast). Official Journal of the European Union 2017. Brussels, 2008/0223; Article 2 https://energystepcode.ca/.
[15] UK Ministry of Housing. Communities & Local Government. 2010 to 2015 government policy: energy efficiency in buildings Retrieved https://www.gov.uk/government/publications/2010-to-2015-government-policy-energy-efficiency-in-buildings/2010-to-2015-government-policy-energy-efficiency-in-buildings); 2015, Accessed date: 1 October 2018.
[16] 2014 basic energy plan of Japan Retrieved http://www.meti.go.jp/english/press/2014/0411_02.html; 2014, Accessed date: 1 October 2018.
[17] C40. C40 South Africa buildings Programme Retrieved https://www.sustainable.org.za/project.php?id = 58; 2018, Accessed date: 1 October 2018.
[18] Ministry of housing and Urban-Rural development of the people's Republic of China (MOHURD) GB 50352-2005 Code for Design of Civil Buildings2005.
[19] Climate zone - Australian Bureau of Statistics Retrieved http://www.abs.gov.au/ausstats/abs@.nsf/Lookup/by%20Subject/4671.0 ~ 2012 ~ Main %20Features ~ Climate%20zone ~ 17; 2012, Accessed date: 1 October 2018.
[20] Standard 169-2013, climatic data for building design standards—standard climate zone maps and data for 5,564 worldwide locations from ASHRAE research project RP-1453, as published in the 2009 ASHRAE Handbook—Fundamentals.
[21] Pacofoc Northwest National Laboratory. Guide to determining climate regions by county Pacific. Building Technologies Office. https://www.energy.gov/sites/prod/files/2015/10/f27/ba_climate_region_guide_7.3.pdf; August 2015.
[22] Urge-Vorsatz Diana, Petrichenko Ksenia, Antal Miklos, Staniec Maja, Eren Ozden, Labzina Elena. Best practice policies for low carbon & energy building based on Scenarios analysis Global Buildings Performance Network (GBPN). 2012.
[23] Lu Y, Wang S, Shan K. Design optimization and optimal control of grid-connected and standalone nearly/net zero Energy buildings. Appl Energy 2015;155:463–77https://doi.org/10.1016/j.apenergy.2015.06.007.
[24] Li DHW, Yang L, Lam JC. Zero Energy buildings and sustainable development Implications - a review. Energy 2013;54:1–10https://doi.org/10.1016/j.energy.2013.01.070.
[25] Cao X, Dai X, Liu J. Building Energy-consumption status worldwide and the state-of-the-Art Technologies for zero-Energy buildings during the past decade. Energy Build 2016;128:198–213https://doi.org/10.1016/j.enbuild.2016.06.089.
[26] World map of 360 international known net zero Energy buildings Retrieved http://batchgeo.com/map/net-zero-energy-buildings, Accessed date: 1 October 2018.
[27] Sun X, Gou Z, Siu-Yu Lau S. Cost-Effectiveness of active and passive design strategies for Existing building retrofits in Tropical climate: case study of a zero Energy building. J Clean Prod 2018;183:35–45https://doi.org/10.1016/j.jclepro.2018.02.137.
[28] Gamage W, Lau S, Qin H, et al. Effectiveness of air-well type courtyards on moderating thermal environments in tropical Chinese Shophouse. Architect Sci Rev 2017;60(6):493–506.
[29] IEA. World energy Outlook 2017 2017 Paris: OECD/IEA; 2017 Retrieved www.iea.org/weo2017/, Accessed date: 1 October 2018.
[30] Bureau of energy efficiency. Ministry of Power, Government of India; 2018 Retrieved www.beestarlabel.com/Home/EnergySavings), Accessed date: 1 October 2018.
[31] International Energy Agency/Organisation for Economic Co-operation and Development. The future of cooling opportunities for Energy- Efficient air conditioning. http://www.iea.org/publications/freepublications/publication/The_Future_of_Cooling.pdf; 2018. 1–92.
[32] de Dear RJ, Brager GS. Developing an adaptive model of thermal comfort and preference. ASHRAE Transact 1998;104:145–67.
[33] Tuohy P, Roaf S, Nicol F, Humphreys M, Boerstra A. Twenty first century standards for thermal comfort: fostering low carbon building design and operation. Architect Sci Rev 2010;53:78–86.
[34] Drake S, de Dear R, Alessi A, Deuble M. Occupant comfort in naturally ventilated and mixed-mode spaces within air-conditioned offices. Architect Sci Rev 2010;53:297–306.
[35] Rai Varun, Robinson Scott A. Agent-based modeling of Energy Technology adoption: Empirical integration of social, behavioral, Economic, and Environmental factors. Environmental Modelling and Software 2015;70:163–77.
[36] Porse Erik, Derenski Joshua, Gustafson Hannah, Elizabeth Zoe, Pincetl Stephanie. Structural, geographic, and social factors in urban building Energy use: analysis of Aggregated account-level consumption data in a megacity. Energy Policy 2016;96:179–92.
[37] Park Eunil, Ohm Jay Y. Factors influencing the public Intention to use renewable Energy Technologies in South Korea: Effects of the fukushima nuclear Accident. Energy Policy 2014;65:198–211.
[38] Sanquist Thomas F, Orr Heather, Shui Bin, Bittner Alvah C. Lifestyle factors in U.S. Residential Electricity consumption. Energy Policy 2012;42:354–64.
[39] Gifford Robert, Nilsson Andreas. Göteborgs universitet, gothenburg University, Samhällsvetenskapliga fakulteten, Psykologiska institutionen, department of Psychology, and faculty of social sciences. "Personal and social factors that influence pro-environmental concern and Behaviour: a review. Int J Psychol 2014;49(3):141–57.
[40] Deuble MP, de Dear RJ. Green occupants for green buildings: the missing link? Build Environ 2012;56:21–7.
[41] Bagci B. Towards a zero energy island. Renew Energy 2009;34:784–9.
[42] Torcellini P, Pless S, Deru M, Crawley D. Zero energy buildings: a critical look at the definition. National Renewable Energy Laboratory and U.S. Department of Energy; 2006.
[43] Zhang J, Zhou N, Hinge A, Feng W, Zhang S. Governance strategies to achieve zero-energy buildings in China. Build Res Inf 2016;44(5–6):604–18. https://doi.org/10.1080/09613218.2016.1157345.
[44] Marszal AJ, Heiselberg P, Bourrelle J, Musall E, Voss K, Sartori I, Napolitano A. Zero Energy Building–a review of definitions and calculation methodologies. Energy Build 2011;43(4):971–9.
[45] Sartori I, Napolitano A, Voss K. Net zero energy buildings: a consistent definition framework. Energy Build 2012;48:220–32.
[46] Ayoub J. Towards net zero energy solar buildings. Fact sheet. International Energy Agency (IEA); 2013.
[47] U.S. Department of Energy. A common definition for zero Energy buildings Retrieved http://energy.gov/sites/prod/files/2015/09/f26/bto_common_definition_zero_energy_buildings; September 2015, Accessed date: 1 October 2018 22.
[48] Pless S, Torcellini P. Net Zero energy building: a classification system based on renewable energy supply options Golden, CO: NREL/TP-550-44586 June 2010.
[49] New ASHRAE zero Energy standard could bring Industry into Agreement. https://www.ashrae.org/news/esociety/new-ashrae-zero-energy-standard.
[50] China Academy of Building Research (CABR). Personal communication on draft nearly zero energy building standards. 2019.
[51] NBI. 2018 getting to zero status Update and list of zero Energy projects Retrieved. https://newbuildings.org/resource/2018-getting-zero-status-update/; 2018, Accessed date: 1 October 2018.
[52] HPB. High performing buildings. Case Studies. Banking on net zero. http://www.hpbmagazine.org/attachments/article/12150/15W-PNC-Net-Zero-Bank-Branch-Ft.%20Lauderdale-Florida.pdf; 2015.
[53] Tropical Net Zero. Stephen Wittkopf. Building and construction Authority of Singapore. High Performing Buildings, Spring 2015. Copyright 2015 ASHRAE. Posted at www.hpbmagazine.org.
[54] The American Institute of Architects. Hawaii gateway energy center. http://www.aiatopten.org/node/142.
[55] Cheng Vincent S, Tong Jimmy C. Building Sustainability in east Asia. United Kingdom: John Wiley & Sons Ltd; 2017. p. 154–8.
[56] Hoeft T. Suburban solution. High performance buildings. Spring; 2012http://www.hpbmagazine.org/attachments/article/12034/12Sp-Magnify-Credit-Union-South-Lakeland-Branch-Lakeland-FL.pdf.
[57] Kennedy Space Center. reen Touches energize Kennedy's newest facility. G. 2011https://www.nasa.gov/centers/kennedy/news/propnorthopens.html.
[58] Living buildings challenge certified case study, zero energy certified, Hadera kindergarten. https://living-future.org/lbc/case-studies/lakeline-learning-center-2/.
[59] Living Buildings Challenge Certified Case Study. Zero energy certified, Lakeline learning center. https://living-future.org/lbc/case-studies/lakeline-learning-center/.
[60] Living Buildings Challenge Certified Case Study. Net Zero energy certified, Vall homes prototype1. https://living-future.org/lbc/case-studies/vali-homes-prototype/.
[61] Living Buildings Challenge Certified Case Study. Zero energy certified, Willow brook house. https://living-future.org/lbc/case-studies/willowbrook-house/.
[62] Living Buildings Challenge Certified Case Study. Net Zero energy certified, American samoaepa office. https://living-future.org/lbc/case-studies/american-samoa-epa-office/.
[63] Living Buildings Challenge Certified Case Study. Net Zero energy certified, DPR constructions phoenix regional office. https://living-future.org/lbc/case-studies/dpr-constructions-phoenix-regional-office/.
[64] HPB. High performing buildings. Case Studies. http://www.hpbmagazine.org/attachments/article/11816/14Sp-DPR-Construction-Phoenix-Regional-Office-Phoenix-AZ.pdf; 2014.

[65] Construction 21, building, Zhuhai Xingye new Energy Industrial Park R&D building. https://www.construction21.org/case-studies/cn/zhuhai-xingye-new-energy-industrial-park-r-d-building.html.
[66] U.S. Department of Commerce. Annual degree Days to selected bases 1971 – 2000. Climatography of the United States No. 81 supplement No. 2. 2002. https://www.ncdc.noaa.gov/climatenormals/clim81_supp/CLIM81_Sup_02.pdf.
[67] Weather Underground. Historical weather from may 2, 2017 to may 3, 2018. https://www.wunderground.com/history.
[68] National Oceanic and Atmospheric Administration. City Precipitation for 1981–2010 normals (mm). https://www.ncdc.noaa.gov/cag/city/mapping.
[69] Meteorological Service Singapore. Climate of Singapore Retrieved http://www.weather.gov.sg/climate-climate-of-singapore/, Accessed date: 1 October 2018.
[70] Climate-data. Climate: Reunion Retrieved https://en.climate-data.org/europe/france/reunion-718/, Accessed date: 1 October 2018.
[71] Hong Kong Observatory. Climate of Hong Kong Retrieved https://www.weather.gov.hk/cis/climahk_e.htm, Accessed date: 1 October 2018.
[72] The weather of timeanddate. https://www.timeanddate.com/.
[73] SHC TASK 40- ECBCS ANNEX 52 Retrieved http://www.iea-shc.org/task40/, Accessed date: 1 October 2018.
[74] Fong KF, Lee CK. Towards net zero energy design for low-rise residential buildings in subtropical Hong Kong. Appl Energy 2012;93:686–94.
[75] ILFI. Living buildings challenge certified case study. https://living-future.org/lbc/case-studies/; 2019.
[76] Solar Heating and Cooling Program. Solution sets and net zero Energy buildings: a review of 30 net ZEBs case studies worldwide. A report of Subtask C may 2014 - Posted: 2014-06-23 by françois garde and michael Donn. SHC TASK 40- ECBCS ANNEX 52. http://www.iea-shc.org/task40/.
[77] Halawa Edward, Ali Ghaffarianhoseini, Ghaffarianhoseini Amirhosein, Trombley Jeremy, Hassan Norhaslina, Baig Mirza, Yusmah Yusoff Safiah, Azzam Ismail Muhammad. A review on Energy conscious designs of building façades in hot and humid climates: Lessons for (and from) Kuala Lumpur and Darwin. Renew Sustain Energy Rev 2018;82:2147–61.
[78] Guan L. Energy use, indoor temperature and possible adaptation strategies for air-conditioned office buildings in face of global warming. Build Environ 2012;55:8–19.
[79] Wan KKW, Li DHW, Lam JC. Assessment of climate change impact on building energy use and mitigation measures in subtropical climates. Energy 2011;36:1404–14.
[80] Lou Siwei, Ernest K, Tsang W, Danny HW, Li Eric WM, Lee, Lam Joseph C. Towards zero Energy school building designs in Hong Kong. Energy Procedia 2017;105:182–7.
[81] Fong KF, Lee CK. Towards net zero Energy design for low-rise residential buildings in subtropical Hong Kong. Appl Energy 2012;93:686–94.
[82] Pan Wei, Pan Mi. A Dialectical system framework of zero carbon Emission building policy for high-rise high-density cities: Perspectives from Hong Kong. J Clean Prod 2018;205:1–13.
[83] Huang Zhijia, Lu Yuehong, Wei Mengmeng, Liu Jingjing. Performance analysis of optimal designed hybrid Energy systems for grid-connected nearly/net zero Energy buildings. Energy 2017;141:1795–809.
[84] Burgett Joseph M, Chini Abdol R, Paul Oppenheim. Specifying residential retrofit Packages for 30 % reductions in Energy consumption in hot–humid climate zones. Energy Efficiency 2013;6(3):523–43.
[85] Kneifel J. Beyond the code: energy, carbon, and cost savings using conventional technologies. Energy Build 2011;43:951–9.
[86] ANSI/ASHRAE/IES standard 90.1-2016. https://www.energycodes.gov/resource-center/training-courses/ansiashraeies-standard-901-2016.
[87] U.S. Department of Energy. Energy saver—types of insulation Retrieved http://energy.gov/energysaver/types-insulation; 2015, Accessed date: 1 October 2018.
[88] Cao M, Rosado P, Lin Z, et al. Cool roofs in Guangzhou, China: outdoor air temperature reductions during heat waves and typical summer conditions. Environ Sci Technol 2015;49(24):14672–9.
[89] Levinson R, Akbari H. Potential benefits of cool roofs on commercial buildings: conserving energy, saving money, and reducing emission of greenhouse gases and air pollutants. Energy Efficiency 2010;3(1):53.
[90] Akbari H, Levinson R. Evolution of cool-roof standards in the United States. BAdv Build Energy Res 2008;2(1):1–32.
[91] Lu S, Chen Y, Liu S, et al. Experimental research on a novel energy efficiency roof coupled with PCM and cool materials. Energy Build 2016;127:159–69.
[92] Lu S, Tong H, Pang B. Study on the coupling heating system of floor radiation and sunspace based on energy storage technology. Energy Build 2018;159:441–53.
[93] Besir AB, Cuce E. Green roofs and facades: a comprehensive review. Renew Sustain Energy Rev 2018;82:915–39.
[94] Haque MT, Tai L, Ham D. Landscape design for energy efficiency. Clemson, South Carolina: Clemson University Digital Press; 2004.
[95] Mazria E. The passive solar energy Book: a Complete guide to passive solar home, greenhouse and building design Paperback. 1979.
[96] Tan J, Tan X. Architect Xia Shichang. CN. Press of South China University of Technology; 2012. [in Chinese)].
[97] Tzempelikos A, Athienitis AK. The impact of shading design and control on building cooling and lighting demand. Sol Energy 2007;81:369–82.
[98] Cho J, Yoo C, Kim Y. Viability of exterior shading devices for high-rise residential buildings: case study for cooling energy saving and economic feasibility analysis. Energy Build 2014;82:771–85.
[99] Al-Masrani SM, Al-Obaidi KM, Zalin NA, et al. Design optimisation of solar shading systems for tropical office buildings: challenges and future trends. Sol Energy 2018;170:849–72.
[100] Lee ES, Selkowitz SE, Clear RD, et al. Advancement of electrochromic windows [R]. Berkeley, CA (US): Ernest Orlando Lawrence Berkeley NationalLaboratory; 2006.
[101] Sullivan R, Lee ES, Papamichael K, et al. Effect of switching control strategies on the energy performance of electrochromic windows[C]//Optical materials Technology for Energy Efficiency and solar Energy conversion XIII. International Society for Optics and Photonics 1994;2255:443–56.
[102] Aldawoud A. Conventional fixed shading devices in comparison to an electrochromic glazing system in hot, dry climate. Energy Build 2013;59:104–10.
[103] Bahaj ABS, James PAB, Jentsch MF. Potential of emerging glazing technologies for highly glazed buildings in hot arid climates. Energy Build 2008;40(5):720–31.
[104] Yu J, Yang C, Tian L. Low-energy envelope design of residential building. Energy Build 2008;40:1536–46.
[105] ASHRAE. Advanced energy design guide for small to Medium office buildings. 2014.
[106] Kubota T, Ahmad S. Wind environment evaluation of neighborhood areas in major towns of Malaysia. J Asian Archit Build Eng 2006;5(1):199–206.
[107] Kubota T, Chyee DTH. Potential of passive cooling techniques for modern houses in the tropical climate of Malaysia—analysis of the indoor thermal environment for various ventilation strategies. Int J Vent 2010;9(1):11–23.
[108] Standard A. Standard 55-2013. Thermal environmental conditions for human occupancy. 2013.
[109] Jadhav NY. Green and smart buildings: advanced technology options. Singapore: Springer; 2016. p. 73–4.
[110] Vangtook P, Chirarattananon S. Application of radiant cooling as a passive cooling option in hot humid climate. Build Environ 2007;42:543–56.
[111] Karmann C, Bauman F, Raftery P, et al. Effect of acoustical clouds coverage and air movement on radiant chilled ceiling cooling capacity. Energy Build 2018;158:939–49.
[112] Shin MS, Rhee KN, Park SH, et al. Enhancement of cooling capacity through open-type installation of cooling radiant ceiling panel systems. Build Environ 2019;148:417–32.
[113] Kim MK, Liu J, Cao SJ. Energy analysis of a hybrid radiant cooling system under hot and humid climates: a case study at Shanghai in China. Build Environ 2018;137:208–14.
[114] ASHRAE. Advanced energy design guide for small to Medium office buildings. 2014.
[115] Zhang T, Liu X, Jiang Y. Development of temperature and humidity independent control (THIC) air-conditioning systems in China—a review. Renew Sustain Energy Rev 2014;29:793–803.
[116] Zhao K, Liu XH, Zhang T, et al. Performance of temperature and humidity independent control air-conditioning system in an office building. Energy Build 2011;43(8):1895–903.
[117] National Renewable Energy Laboratory. Transforming Energy. https://buildingdata.energy.gov/project/hawaii-gateway-energy-center.
[118] Natural Energy Laboratory of Hawaii. http://www.nelha.org.
[119] ASHRAE. Advanced Energy design guide for small to medium office buildings. 2014.
[120] Hee W, Alghoul M, Bakhtyar B, Elayeb O, Shameri M, Alrubaih M, Sopian K. The role of window glazing on daylighting and energy saving in buildings. Renew Sustain Energy Rev 2015;42:323–43.
[121] Li DHW, Yang L, Lam JC. Impact of climate change on energy use in the built environment in different climate zones — a review. Energy 2012;42:103–12.
[122] de Bakker C, Aries M, Kort H, Rosemann A. Occupancy-based lighting control in open-Plan office spaces: a state-of-the-Art review. Build Environ 2017;112:308–21https://doi.org/10.1016/j.buildenv.2016.11.042.
[123] Haq MAU, et al. A review on lighting control Technologies in commercial buildings, Their performance and affecting factors. Renew Sustain Energy Rev 2014;33:268–79.
[124] Bantis F, et al. Current status and recent achievements in the field of Horticulture with the Use of light-Emitting diodes (LEDs). Sci Hortic 2018;235:437–51https://doi.org/10.1016/j.scienta.2018.02.058.
[125] Montoya FG, Peña-García A, Juaidi A, Manzano-Agugliaro F. Indoor lighting Techniques: an overview of Evolution and new Trends for Energy saving. Energy Build 2017;140:50–60.
[126] Chitnis D, Thejo kalyani N, Swart HC, Dhoble SJ. Escalating opportunities in the field of lighting. Renew Sustain Energy Rev 2016;64:727–48.
[127] Huang BJ, Hsu PC, Wu MS, Tang CW. Study of system dynamics model and control of a high power LED lighting luminaire. Energy 2007;32:2187–98.
[128] Wang Q, Xu H, Zhang F, Wang Z. Influence of color Temperature on comfort and preference for LED indoor lighting. Optik 2017;129:21–9https://doi.org/10.1016/j.ijleo.2016.10.049.
[129] Lowry G. Energy saving claims for lighting controls in commercial buildings. Energy Build 2016;133:489–97.
[130] Xiong J, Tzempelikos A. Model-based shading and lighting controls considering visual comfort and energy use. Sol Energy 2016;134:416–28.
[131] U.S. Department of Energy. Adoption of light-Emitting diodes in common lighting applications. https://energy.gov/sites/prod/files/2015/07/f24/led-adoption-report_2015.pdf; July 2015.
[132] Thornton BA, Wang W, Lane MD, Rosenberg MI, Liu B. Technical support document: 50% energy savings design technology Packages for Medium office buildings. PNNL-19004. Richland, WA: Pacific Northwest National Laboratory; 2009.
[133] EIA. Commercial building energy Survey, energy usage summary. Washington, D.C.: U.S. Energy Information Administration; 2012https://www.eia.gov/consumption/commercial/.
[134] 2015GB. Public building energy efficiency design standards[S][D]. 2015.

[135] ASHRAE. Advanced Energy design guides. https://www.ashrae.org/technical-resources/aedgs; 2018.
[136] Guangdong Provincial Academy of Building Research. Feasibility study report of Pearl River city low energy demonstration project. 2016.
[137] Assaf J, Shabani B. Multi-objective sizing optimisation of a solar-thermal system integrated with a solar-hydrogen combined heat and power system, using genetic algorithm. Energy Convers Manag 2018;164:518–32.
[138] Sterling SJ, Collins MR. Feasibility analysis of an indirect heat pump assisted solar domestic hot water system. Appl Energy 2012;93:11–7.
[139] [2Budihardjo I, Morrison GL. Performance of water-in-glass evacuated tube solar water heaters. Sol Energy 2009;83(1):49–56.
[140] Assaf J, Shabani B. Transient simulation modelling and energy performance of a standalone solar-hydrogen combined heat and power system integrated with solar-thermal collectors. Appl Energy 2016;178:66–77.
[141] Chua KJ, Chou SK, Yang WM. Advances in heat pump systems: a review. Appl Energy 2010;87(12):3611–24.
[142] Kim T, Choi BI, Han YS, et al. A comparative investigation of solar-assisted heat pumps with solar thermal collectors for a hot water supply system. Energy Convers Manag 2018;172:472–84.
[143] Liang X. Emerging power quality challenges due to integration of renewable Energy sources. IEEE Trans Ind Appl 2017;53(2):855–66.
[144] Tuballa ML, Abundo ML. A review of the development of Smart Grid technologies. Renew Sustain Energy Rev 2016;59:710–25.
[145] Luhmann T, et al. An approach for cost-Efficient grid integration of distributed renewable Energy sources. Engineering 2015;1(4):447–52http://linkinghub.elsevier.com/retrieve/pii/S209580991630025X.
[146] Nykamp S, Molderink A, Hurink JL, Smit GJM. Statistics for PV, wind and Biomass generators and Their impact on distribution grid planning. Energy 2012;45(1):924–32https://doi.org/10.1016/j.energy.2012.06.067.
[147] Khan MJ, Iqbal MT. Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland. Renew Energy 2005;30(6):835–54.
[148] Dufo-López R, Bernal-Agustín JL, Contreras J. Optimization of control strategies for stand-alone renewable energy systems with hydrogen storage. Renew Energy 2007;32(7):1102–26.
[149] BPIE (Buildings Performance Institute Europe). Opening the door to smart buildings Brussels http://bpie.eu/publication/opening-the-door-to- smart-buildings/; 2017.
[150] International Energy Agency (IEA). For the global Alliance for buildings and construction (GABC). Global status report 2017. 2017.
[151] Frontczak M, Wargocki P. Literature survey on how different factors influence human comfort in indoor environments. Build Environ 2011;46(4):922–37http://doi.org/10.1016/j.buildenv.2010.10.021.
[152] Levermore GJ. Building energy management systems. Build Serv Eng Technol 1993;14:B1–18.
[153] Grözinger J, et al. Optimising the energy use of technical building systems – unleashing the power of the EPBD's Article 8. Ecofyswww.ecofys.com/en/publications/optimising%2dthe%2denergy%2duse%2dof%2dtechnical%2dbuilding%2dsystems.
[154] Sav von Manteuffel B, Offermann M, Bettgenhäuser K. Energy and GHG emission savings potentials of thermostatic valves Final Report Ecofys; 2015
[155] Hirschberg R. Energy efficiency related to the change of thermostatic radiator valves. Ehocheffizienzhaus Institut; 2016.
[156] Badescu V, Laaser N, Crutescu R. Warm season cooling requirements for passive buildings in Southeastern Europe (Romania). Energy 2010;35:3284–300.
[157] Roussac AC, Steinfeld J, de Dear R. A preliminary evaluation of two strategies for raising indoor air temperature setpoints in office buildings. Architect Sci Rev 2011;54:148–56.
[158] Sadineni SB, Boehm RF. Measurements and simulations for peak electrical load reduction in cooling dominated climate. Energy 2012;37:689–97.
[159] Sun YJ, Huang P, Huang GS. A multi-criteria system design optimization for net zero energy buildings under uncertainties. Energy Build 2015;97:196–204.
[160] Aelenei L, Gonçalves H. From solar building design to net zero energy buildings: performance insights of an office building. Energy Procedia 2014;48:1236–43.
[161] Lu Y, Wang S, Yan C, Shan K. Impacts of renewable Energy system design Inputs on the performance Robustness of net zero Energy buildings. Energy 2015 2015;93(2):1595–606. 15 December.
[162] Zhang S, Huang P, Sun Y. A multi-criterion renewable Energy system design optimization for net zero Energy buildings under uncertainties. Energy 2016;94:654–65https://doi.org/10.1016/j.energy. 2015.11.044.
[163] Sun Y, Huang P, Huang G. A multi-criteria system design optimization for net zero Energy buildings under uncertainties. Energy Build 2015;97:196–204https://doi.org/10.1016/j.energy.2015.11.044.
[164] Lu Y, Wang S, Yan C, Huang Z. Robust optimal design of renewable Energy system in nearly/net zero Energy buildings under uncertainties. Appl Energy 2017;187:62–71.
[165] Sun Y. Sensitivity analysis of macro-parameters in the system design of net zero energy building. Energy Build 2015;86:464–77.
[166] Fesanghary M, Asadi S, Geem ZW. Design of low-emission and energy- efficient residential buildings using a multi-objective optimization algorithm. Build Environ 2012;49:245–50.
[167] Hamdy M, Hasan A, Siren K. Applying a multi-objective optimization approach for design of low-emission cost-effective dwellings. Build Environ 2011;46(1):109–23.
[168] Nguyen A-T, Reiter S, Rigo P. A review on simulation-based optimization methods applied to building performance analysis. Appl Energy 2014;113:1043–58.
[169] Commercial building - Pacific northwest national Laboratory. https://www.pnnl.gov/main/publications/external/technical_reports/pnnl-22045.pdf.
[170] Getting to zero status Update and list of zero Energy projects. https://newbuildings.org/wp-content/uploads/2018/01/GTZ_2018_List.pdf; 2018.
[171] ASHRAE. Net zero Energy building guideline. https://www.ashrae.org/technical-resources/aedgs/zero-energy-aedg-free-download; 2019.
[173] D'Agostino D, Mazzarella L. What is a nearly zero energy building? Overview, implementation and comparison of definitions. Journal of Building Engineering 2018.
[174] Guillén-Lambea S, Rodríguez-Soria B, Marín JM. Comfort settings and energy demand for residential nZEB in warm climates. Appl Energy 2017;202:471–86.
[175] National building code. https://www.scribd.com/doc/23575885/National-Building-Code-2005; 2005.
[176] Chastas Panagiotis, Theodosiou Theodoros, Bikas Dimitrios. Embodied energy in residential buildings-towards the nearly zero energy building: a literature review. Build Environ 2016;105:267–82https://doi.org/10.1016/j.buildenv.2016.05.040.
[177] U.S. department of energy, building technologies office, Banking on Energy Efficiency. https://www1.eere.energy.gov/buildings/publications/pdfs/corporate/bankofamerica_casestudy_092013.pdf; 2013.
[173] Metabolism of cities. https://metabolismofcities.org/data/subareas/27.
[174] BIZEE. Degree Days, weather data for Energy Professionals. https://www.degreedays.net/.
[175] C40 China buildings Programme (CBP): Launch report. https://www.c40.org/researches/constructing-a-new-low-carbon-future-china.
[176] Germany NZEB Roadmap. http://www.nzeb.in/wp-content/uploads/2015/09/Germany-NZEB-Roadmap.pdf.
[177] Energy Efficiency trends and policies in Italy. http://www.odyssee-mure.eu/publications/national-reports/energy-efficiency-italy.pdf.
[178] Zero Emission buildings in Korea. https://sciforum.net/manuscripts/2443/manuscript.pdf.
[179] Zero carbon Australia buildings plan. http://media.bze.org.au/bp/bze_buildings_plan_v1.0.3.pdf.
[180] Super low Energy buildings Technology Roadmap. https://www.bca.gov.sg/GreenMark/others/SLE_Tech_Roadmap.pdf.
[181] Zero Energy building in Malaysia by SEDA Malaysia. https://www.slideshare.net/asetip/zero-energy-building-in-malaysia-by-seda-malaysia.
[182] Zero Energy building added to ASEAN Energy Awards. http://www.aseanenergy.org/articles/zero-energy-building-added-to-asean-energy-awards-2019/; 2019.
[183] China green building evaluation label. http://www.cngb.org.cn/.