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A Review of the Application of the Nearly Zero Energy Building Concept in Different Climates

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Abstract— The building sector consumes about 30% of the world's primary energy demand. Conventionally, reducing building energy consumption is done through energy saving or energy conservation activities. Nearly zero energy building (nZEB) itself can be defined as a provision that implies a value of energy consumption that is as low as possible or an energy-efficient building, then determines the energy source that is able to meet these energy needs. These strategies can generally be done with passive design, active design, and comprehensive energy management approaches [6]. This article presents an overview of the implementation of nZEB and finds out the shortcomings in terms of strategies and techniques used for different types of buildings and climates. Given the differences in climate and building characteristics, we found that each region has different challenges in applying the nZEB concept.

Keywords: Nearly zero energy building, Climate change and Energy efficiency.

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1. Introduction

Currently, about 30% of the world's primary energy demand is consumed by the building sector. Conventionally, reducing building energy consumption is done through energy saving or energy conservation activities. One approach to increase energy reduction in the building sector is energy conservation on the usage side [1]. According to statistical calculations, there is a potential for 20-40% energy savings in the building sector if measures can be taken to improve building energy efficiency [2], [3]. Potential savings of 9-12% can also be obtained from energy management in the education sector [4].

In general, four parameters indicate a space's environmental quality: air quality, thermal comfort, acoustic comfort, and visual comfort [5]. In realizing the nZEB concept in Indonesia, it is necessary to follow the idea of buildings with high energy efficiency that has been applied in several European countries. Passive design approaches can be taken in form, orientation, insulation, and windows), building support systems (e.g., heating, ventilation, and air conditioning (HVAC) systems, hot water supply, lighting systems, electrical equipment, and control management), and energy efficiency design for buildings with specific weather conditions (e.g., outdoor air temperature, relative humidity, solar radiation, and wind speed).

The Zero Energy Building (ZEB) concept is that buildings can fulfill all their energy needs from cheaper, locally available, non-polluting, and renewable sources [6]. The basic idea of ZEB is how to design a building with zero energy use by maintaining the balance between the energy needed and the energy that can be generated in a building. Based on these conditions, the various definitions of the ZEB concept will affect the chosen approach. The reference must be established to get a more effective approach related to technology in the building field.

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Meanwhile, the concept of nearly zero energy building (nZEB) itself can be defined as a provision that implies a value of energy consumption that is as low as possible or an energy-efficient building, then determines the energy source that is able to meet these energy needs [7]. The nZEB concept is a high-performance building, which is indicated by a very low building energy requirement that can be partially met from renewable energy sources [8].

Buildings with intelligent systems can also drive the movement towards a more optimized energy use perspective. These systems can encourage the development of sustainable technologies and decrease carbon emissions, operational costs, productivity, well-being, energy consumption, and comfort[9]. Currently, there are several types of buildings depending on the design objectives. For example, there are green, zero-energy, and smart buildings, as seen in Figure 1.

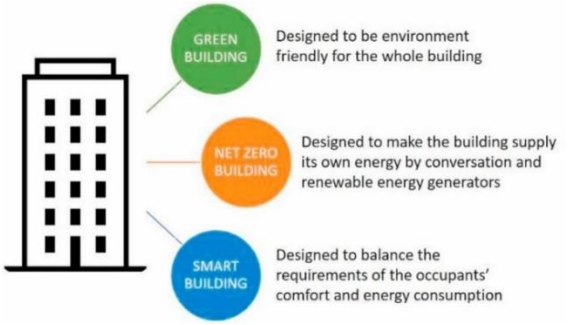


Figure 1. Types of building concepts based on their purpose according to [10]

Energy efficiency strategies are needed. Reducing building energy demand by improving building characteristics, using energy-efficient equipment and technology as well as the behavior of occupants are strategies for energy efficiency [10]. It can be done with passive design, active design, and comprehensive energy management approaches [6]. This review aims to provide an overview of the implementation of nZEB and to find out the shortcomings in terms of strategies and techniques used for different types of buildings and regions. Solar radiation is an essential factor in the application of nZEB. Design strategies to utilize and anticipate the potential of sunlight in the tropics.

2. Method

The research method can be described as follows:

- Article search procedure: A keyword-based search was conducted using existing journal databases, including Science Direct. Keywords such as "nearly zero energy building AND climates". Furthermore, papers were selected based on the type of review articles published from 2017 - 2023.
- Article filtering: The results of the article search procedure from both databases were imported into Zotero (reference manager) to be filtered by title, keywords, and abstract so that the unrelated articles were removed.
- Selection of sub-topics: After reviewing the remaining articles, an analysis is performed based on keywords, selecting which sub-topics and making them easily organized.
- New article search: Once the sub-topics are determined, a new search is performed in the database, merging the sub-topics with the main topic. Then article filtering is done again, removing duplicate articles and out-of-topic articles.

Review ini meninjau studi-studi yang pernah ada untuk berbagai jenis bangunan di berbagai daerah dengan iklim yang berbeda. Struktur makalah ini adalah: Bagian metode menyajikan metode yang digunakan dalam review ini. Bagian selanjutnya memberikan ringkasan studi yang ada terkait penerapan nZEB. Bagian akhir merupakan kesimpulan.

Our paper reviews existing studies for different building types in different climatic regions. The structure of this paper is as follows: The methods section presents the methods used in this review. The following section summarizes existing studies related to the application of nZEB. The last section is the conclusion.

3. Result and Discussion

The nZEB concept generally aims to achieve near-zero energy use [11]. The smart building concept combines technology and energy systems in buildings. It focuses on automation, resource management, occupant comfort, and energy conservation [12]. How to balance the needs of energy use and occupant comfort is the biggest issue in intelligent buildings. The three primary considerations determining occupant comfort in buildings are air quality, visual and thermal comfort [13]. This review focuses on the strategies different regions with different climates have adopted to achieve building energy efficiency. It also discusses various studies that have been conducted as an application of nZEB.

Tabel 1. Review of building energy-saving technologies and strategies

Place	Climate (Koppen Classification)	Contribution	Limitation	Ref
Aristotle University of Thessaloniki, Greece	Hot semi-arid climate (Bsh)	An idea for an electrical power management system that relies on a residential DC distribution network	Implementing this idea requires modifications to the distribution network in the home.	[14]
Simulation	Not defined	A method to test the electrical conductivity of buildings using clustering techniques.	This method requires very detailed information on the building structure to obtain complete data on electrical conduction.	[9]
Universitat Politècnica de Catalunya, Spain	Hot-summer Mediterranean climate (Csa)	Control model for managing electrical equipment in residential buildings	The control was only applied to a house with 12 different load types. The optimal setpoint for each load was not formulated.	[15]
Simulation	Not Defined	Forecasting method of thermal energy usage for short-term activities.	The method does not implement a production management strategy that optimizes equipment operation.	[16]
Campobasso, Italy	Humid subtropical climate (Cfa)	Algorithm to utilize the thermal inertia of the building to save energy within the building cluster.	Activities involving all buildings and other factors, such as electric vehicles and shared resources, are not taken into account.	[17]
Virginia,USA	Humid subtropical climate (Cfa)	Assessment of the impact of merging local networks on the commercial sector, such as apartment buildings and districts.	Assessment is conducted with the building, not in full operation	[18]
Porto, Portugal	Warm-summer Mediterranean climate (Csb)	An approach to derive the value of savings obtained for home energy management	The use of this approach is commonly used	[19]

Not Defined	Not Defined	A method to reduce peak load electricity demand in buildings through user load control.	Does not take into account the incorporation of client-side renewable generation with demand-responsive buildings.	[20]
Not Defined	Not Defined	Scheduled load and battery scheduling algorithm for consumers with smart homes.	Energy demand varies depending on the schedule	[21]
Not Defined	Not Defined	Energy management scheme to reduce the overall energy usage of HVAC units.	This scheme was developed for decentralized HVAC systems.	[22]
Not Defined	Not Defined	Peak load shifting in Thermal energy usage for buildings	The results were confirmed on a simulation scale only.	[23]
Karlsruhe, Jerman	Temperate oceanic climate (Cfb)	Energy management system to reduce the peak load observed on the power grid with smart buildings.	Tidak mempertimbangkan sub-sistem yang ada dan sistem HVAC, tetapi hanya kendaraan listrik.	[24]
Simulation	Not Defined	The cost function for MPC ensures thermal comfort with minimal energy utilization and linearization technique for hydronic heating system model.	The thermal control is based on a mono-zone building model, seeing that the climate and estimated load requirements are 100% of the building.	[25]
Not Defined	Not Defined	A model for forecasting and evaluating energy utilization in non-residential buildings	Only one region with a specific climate is considered	[26]
Vienna, Austria	Temperate oceanic climate (Cfb)	Building a hygrothermal model depends on a physical approach to perform optimal control.	The simulation study did not consider the use of ventilation coils in the room.	[27]
Simulation	Not Defined	The model predictive control scheme for cooling and heating systems using predictive data for climate and deep gain	The simulation study did not consider the use of ventilation coils in the room.	[28]
Simulation	Not Defined	An economical MPC technique to minimize the total operating cost of a heating system	It does not combine electricity prices and climate forecasts to see the effects of vulnerability.	[29]
Michigan Technological University, USA	Hot-summer humid continental climate (Dfa)	A productive improvement-based MPC energy management system is suitable for nonlinear energy systems.	Involve non-convex constraints, making the solution only locally optimal.	[30]
Universitat Politècnica de Catalunya, Spain	Hot-summer Mediterranean climate (Csa)	The realtime MPC framework minimizes the energy use and operational costs of HVAC systems with integrated micro-scale concentrated solar power.	Economic assessment and energy analysis of the system were not conducted.	[31]

	Humid subtropical climate (Cfa)	The predictive control technique is based on a neural network for boilers.	Only based on the heating system temperature, internal temperature, and external temperature.	[32]
Simulation	Not Defined	An optimization framework for proficiently controlling HVAC systems in buildings.	Only evaluated one specific type of non-residential building.	[33]
Hongkong	Monsoon-influenced humid subtropical climate (Cwa)	An optimal control system to synchronize HVAC, battery energy storage, and renewable generation.	Humidity and usable temperature-based thermal comfort models are excluded from the control system.	[34]
Hongkong	Monsoon-influenced humid subtropical climate (Cwa)	A method for describing and assessing building energy performance models.	This method only evaluated the performance coefficient of the HVAC system.	[34]
Egypt	Hot deserts climate (BWh)	Neural network predictive control technique for energy management in zero-energy buildings.	Only evaluated residential buildings.	[35]
Helsinki, Finland	Warm-summer humid continental climate (Dfb)	MPC-based control framework planned to reduce energy use in non-residential buildings while ensuring occupant comfort	The design relies on various search heuristics, which may be difficult to improve if several factors are to be simplified simultaneously.	[36]
Simulation	Not Defined	A method for determining the instantaneous equilibrium point temperature of a building.	Needs to be implemented with realtime information.	[37]
Barcelona, Spain	Hot-summer Mediterranean climate (Csa)	Need further exploration at more prominent altitudes	Only evaluated for rooms up to 3 m.	[38]
Stuttgart, Germany	Humid subtropical climate (Cfa)	Use a gray box modeling approach to evaluate the rate of change of air ventilation.	Further assessment at higher altitudes is needed	[39]
Cambridgeshire, UK	Temperate oceanic climate (Cfb)	Hybrid building modeling techniques for HVAC systems with reduced modeling	Using two different modeling methods that require different skill sets from modelers may be an obstacle to their use.	[40]
Siero, Spain Pinkafeld, Austria	Temperate oceanic climate (Cfb)	An indoor building energy and comfort management model that relies on a combination of data.	Not incorporating electric vehicles into the smart building system.	[41]
Torino, Italy	Humid subtropical climate (Cfa)	Methodology for detecting functional sensor deficiencies in hydronic heating systems	Not including water pressure	[42]
Simulation	Not Defined	Methods with time series characterization of energy in buildings	Only considered weekdays were considered	[43]

Oulu, Finland	Subarctic climate (Dfc)	Two techniques for generating information for irregular energy usage in a certain range	The technique depends on the size of the accessible data set.	[44]
Madrid, Spain	Hot-summer Mediterranean climate (Csa)	A method that determines the ideal scheduling of local energy system components.	This method was tested on an emulated medium-sized hotel.	[45]
Singapore	Tropical rainforest climate (Af)	A method for smart buildings to manage energy utilization and overall comfort value.	No proper function shows human activity is included in the calculation of energy use.	[46]
Simulation	Not Defined	Algorithm in controlling air conditioning, mechanical ventilation, and personal fans.	The dynamic model of room energy is obtained from a simplified model	[47]
Not Defined	Not Defined	An approach based on probabilistic data of HVAC temperature	Energy utilization model with on-off control in HVAC systems.	[48]
Suzhou, China	Monsoon-influenced humid subtropical climate (Cwa)	Algorithms used by consumers in ideal load, energy supply, and cost conditions.	It is necessary to consider energy providers and consumers' HVAC systems.	[49]
Bari, Italy	Hot-summer Mediterranean climate (Csa)	Optimization method for estimating realtime usage of energy building	Does not consider the optimization of energy utilization based on usage patterns	[50]
Madrid, Spain	Hot-summer Mediterranean climate (Csa)	A BEMS that integrates enhanced sensor networks using cloud services.	It needs to be proven for the applicability of the settings in various buildings.	[51]

Table 1 provides a summary of various technologies for energy-efficient buildings. In the application of comprehensive energy management, the concept of using a Building Energy Management System (BEMS) has also been widely developed. BEMS can be described as a combination of strategies and methods needed to improve energy performance, efficiency, and use [10]. This technology enables the implementation of energy management functions such as automating the approach to energy use, monitoring the use of energy costs, detecting energy use anomalies, and organizing energy use information [12]. Many studies have discussed the use of BEMS for various subsystems in buildings, such as cooling and heating systems [13], [14] or entire buildings [9], [15].

Table 2. Application of nZEB in different climates

Place	**Climate (Koppen Classification)**	**Energy Generation**	**nZEB approach**		**Ref**
			Passive Design	**Active Design**	
La habana, Cuba	Tropical savanna (Aw)	thermal, Photovoltaic, Wind Turbine	Air ventilation	Lighting Control	[52]
Quito, Ecuador	Temperate oceanic climate (Cfb)	Photovoltaic	Passive solar, thermal insulation	Usage control of heating and air conditioning	[53]

San Salvador, El Salvador	Tropical savanna (Aw)	Photovoltaic	Not Defined	Lighting Control	[45]
Mirebalais, Haiti	Tropical savanna (Aw)	Photovoltaic	Light color wall, Air ventilation, solar radiation	Window Control	[54]
Uruguay	Humid subtropical climate (Cfa)	Photovoltaic	Not Defined	Not Defined	[55]
La Borda, Spanyol	Hot-summer Mediterranean climate (Csa)	Not Defined	facades of heat-shielding materials	air ventilation control	[56]
San Juan, Argentina	Cold desert climate (Bwk)	Photovoltaic	ventilasi udara, kebiasaan pengguna	pengaturan pencahayaan dan beban	[57]
Los Santos, Panama	Tropical rainforest climate (Af)	Photovoltaic	Passive Cooling, Air ventilation, building orientation	control daylighting	[58]
Curitiba, Brazil	Tropical rainforest climate (Af)	BIPV	Optimization of building form and building orientation	Not Defined	[59]
Cartagena, Colombia	Tropical dry savanna climate (As)	Photovoltaic	Building orientation, window and ventilation efficiency	lighting settings, humidity and air conditioner	[60]

In addition, several studies, including in the tropics, show that energy consumption data in buildings is the largest to meet thermal comfort and visual comfort [59]-[61]. In realizing the concept of nZEB in Indonesia, it is necessary to follow the concept of buildings with high energy efficiency that has been applied in several countries in Europe. The approach taken is a passive design approach, active design, and comprehensive energy management [6]. In the passive design approach, it can be done with a building structure with good thermal insulation that requires small electrical energy consumption to condition the air temperature in the building. While building structures that can utilize natural illumination from sunlight will reduce the electricity consumption needed to condition the lighting in the building.

4. Conclusion

Given the differences in climate and building characteristics, each region has different challenges in applying the nZEB concept. The nZEB concept can generally be defined as a near-zero energy building concept by optimizing energy efficiency, utilizing renewable energy, and striving without reducing occupant comfort. Climate parameters such as the amount of solar radiation, wind speed and direction, and air humidity. The largest building energy demand, specifically in climates, including tropical climates, is for cooling needs, and the most significant cooling load is solar radiation. On the other hand, solar energy is also the most practical potential energy source and is available in

sufficient quantities to be converted as electrical energy or for natural lighting. Therefore, solar radiation is an essential factor in the application of nZEB. Design strategies to utilize and anticipate the potential of sunlight in the tropics can be facade design and building orientation. An active design approach can be made by optimizing natural and artificial light sources and thermal comfort in buildings.

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