Chapter

Introduction of ZEB Technology in Japan

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Abstract

It is necessary to reduce energy consumption in order to combat global warming and stabilize energy supply and demand. In particular, final energy consumption in the business sector (buildings such as office buildings and commercial facilities) accounted for about 16.1% of Japan's total in FY2018 database, an increase from about 12.6% in FY1990 database. Therefore, there is a need for the spread of zero-energy building (ZEB), which can significantly reduce the energy consumption in buildings. Since people are active in the building, energy consumption cannot be completely reduced to zero; however, it can be closer to ZEB by reducing the energy used in the building and creating energy in the building as much as possible. This chapter introduces some technologies of energy saving and energy creation to realize ZEB in general buildings in Japan.

Keywords: global warming, zero-energy building, energy saving, passive technology, active technology, creative technology

1. Introduction

A zero-energy building (ZEB), which is also known as a net ZEB, is a building with net zero-energy consumption, meaning the total amount of energy used by the building on an annual basis is equal to the amount of renewable energy created on the site or in other definitions by renewable energy sources offsite, using technologies such as heat pumps, high efficiency windows and insulation, and solar panels [1, 2]. In general, ZEB is a building that aims to reduce the annual balance of primary energy consumed by the building while realizing a comfortable indoor environment. Since people are active in the building, energy consumption cannot be completely reduced to zero; however, it can be set to zero by the means of energy saving and energy creation (as shown in **Figure 1**). Achieving zero energy is an ambitious yet increasingly achievable goal that is gaining momentum across geographic regions and markets. Private commercial property owners have a growing interest in developing ZEBs to meet their corporate goals, and in response to regulatory mandates, federal government agencies and many state and local governments are beginning to move toward ZEB targets [3].

The introduction of ZEBs makes buildings more energy efficient and reduces the rate of carbon emissions once the building is in operation; however, there is still a lot of pollution associated with embodied carbon of buildings [4]. The importance

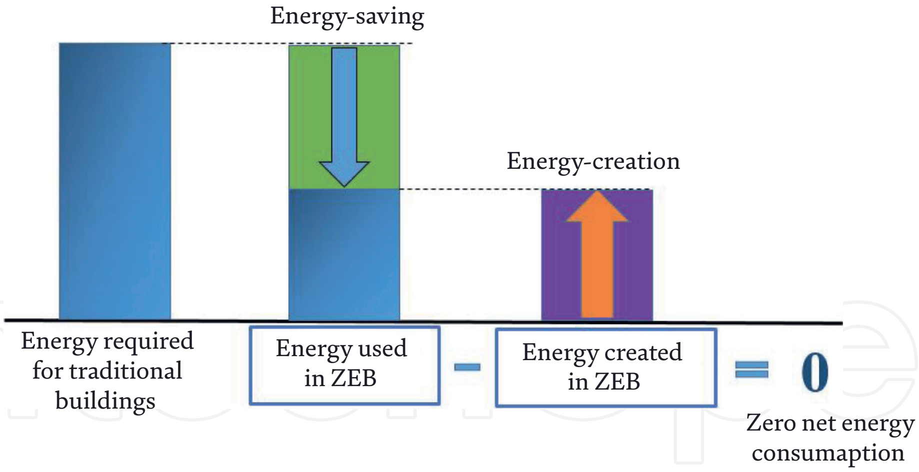

Figure 1.
Conceptual diagram for realizing zero-energy building.

of embodied carbon will grow as it will begin to account for the greater portion of a building's carbon emissions. In some newer and energy efficient buildings, embodied carbon has risen to approximately 47% of the building's lifetime emissions. Focusing on the embodied carbon is part of optimizing construction for climate impact and zero carbon emissions require slightly different considerations from optimizing only for energy efficiency [5]. One way to reduce the embodied carbon is by using low-carbon materials for construction such as straw, wood, linoleum, or cedar. A study reported that for materials such as concrete and steel, options to reduce embodied emissions do exist; however, these are unlikely to be available at large scale in the short term [6].

The ZEBs harvest available energy to meet their electricity and heating or cooling needs. The most common way to harvest energy is to use roof-mounted solar photovoltaic (PV) panels that can turn the solar radiation into electricity. Other common way such as using heat pumps, which can harvest heat and cool from the air (air-sourced) or ground near the building (ground-sourced otherwise known as geothermal), is also adopted to create energy. In the case of individual houses, various microgeneration technologies may be used to provide heat and electricity to the building, by using solar cells or wind turbines for electricity, and biofuels or solar thermal collectors linked to a seasonal thermal energy storage (STES) for space heating. The STES can also be used for summer cooling by storing the cold of winter underground. To cope with fluctuations in demand, ZEBs are frequently connected to the electricity grid, and they export electricity to the grid when there is a surplus and draw electricity from the grid when not enough electricity is being produced.

The most cost-effective steps toward a reduction in a building's energy consumption usually occur during the design process [7]. To achieve efficient energy use, zero-energy design departs significantly from conventional construction practice. The successful ZEB designers typically combine time-tested passive solar, or artificial/fake conditioning, principles that work with the on-site assets. Sunlight and solar heat, prevailing breezes, and the cool of the earth below a building can provide daylighting and stable indoor temperatures with minimum mechanical means. ZEBs are normally optimized to use passive solar heat gain and shading, combined with thermal mass to stabilize diurnal temperature variations throughout the day, and in most climates are super-insulated [8].

Countries around the world have been gradually implementing different policies to tackle ZEB, as a response to global warming and increasing greenhouse gas

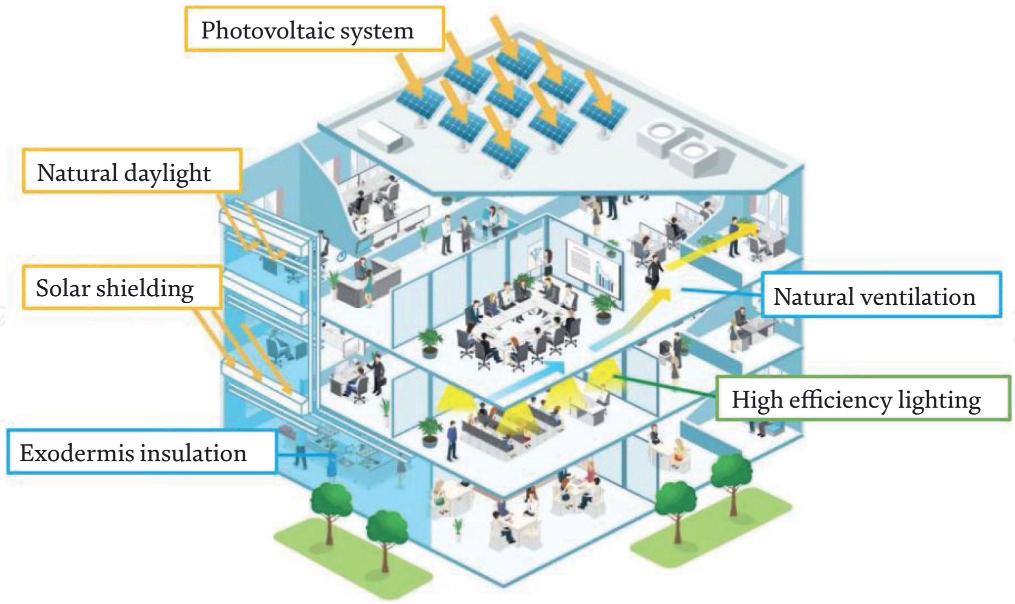

Figure 2.
Conceptual diagram of a general building to which energy-saving technology is applied.

emissions. In 2015, the Paris Agreement was created under the United Nations Framework Convention on Climate Change (UNFCC) with the intent of keeping the global temperature rise of the twenty-first century below 2°C and limiting temperature increase to 1.5°C by limiting greenhouse gas emissions [9]. While there was no enforced compliance, 197 countries signed the international treaty which bound developed countries legally through a mutual cooperation where each party would update its Intended Nationally Determined Contributions (INDC) every 5 years and report annually to the conference of the parties (COP) [10]. Due to the advantages of energy efficiency and carbon emission reduction, ZEBs are widely being implemented in many different countries as a solution to energy and environmental problems within the infrastructure sector [11].

After the March 2011, Fukushima earthquake followed by the up with Fukushima Daiichi nuclear disaster, and Japan experienced severe power crisis that led to the awareness of the importance of energy conservation. In 2012, Ministry of Economy, Trade and Industry (METI), Ministry of Land, Infrastructure, Transport and Tourism (MLIT) and Ministry of the Environment of Japan summarized the road map for low-carbon society, which contains the goal of ZEB to be standard of new construction in 2020 [12]. This chapter introduces the technologies to realize ZEB in general buildings (as shown in **Figure 2**) in Japan, in terms of i) passive technologies (solar shielding, exterior skin insulation, natural daylight, and natural ventilation), ii) active technologies (high-efficiency lighting, high-efficiency air conditioning, etc.), and iii) creation technologies (photovoltaic power generation, biomass power generation, etc.).

2. Passive technologies

Passive technology is a technology for reducing the amount of required energy or energy demand to properly maintain the environment inside a building. It includes solar shielding, exterior skin insulation (walls and windows), natural daylight utilization, and natural ventilation.

2.1 Solar shielding

Solar shielding is a technology that shields the sunlight that enters through the roof, exterior walls, and windows, and suppresses the cooling load. Particularly in the summer, once solar radiation (or heat) enters the room, a large amount of cooling energy is consumed to cool the heat; thus, solar shielding is considered as an important technology to realize a comfortable indoor environment. On the other hand, in winter, it is better to take in a considerable amount of solar heat to reduce the heating load. There is also a need to take in natural daylight well even in the summer from the viewpoint of reducing lighting energy. In this way, it is necessary to consider measures to meet the conflicting performance requirements, such as suppressing the intrusion of solar heat during cooling in the summer and taking in the sunlight during heating in the winter. As shown in **Figure 3**, specific measures to block sunlight at openings include blinds, louvers, eaves, and high-performance glass. By effectively combining these measures, it is possible to successfully cope with multiple conflicting performance requirements as described above.

The blinds are intended to prevent direct sunlight into the room, but they are also expected to work as a daylighting system that takes in natural light as indoor lighting. Recently, a "gradation blind" that efficiently takes in natural light into the room, while preventing the invasion of solar heat by optimally controlling the angle of the blind slats one by one and reflecting the light, has been developed.

The eaves are basically immovable, but by properly designing their length based on the solar altitude and the height of the windows, the sunlight with high solar altitude in summer can be blocked and the sunlight with low solar altitude in winter can be taken in.

For walls and other areas other than openings, the use of plants and materials with high solar reflectance can improve thermal insulation and solar radiation reflectance, thereby improving solar shielding performance.

2.2 Exterior skin insulation

The exterior skin insulation technology includes the use of high-performance exterior wall insulation and high-performance insulating and thermal barrier windows. High-performance exterior wall insulation can reduce the amount of energy required to maintain a comfortable indoor temperature compared to a non-insulated building by controlling the flow of heat in and out of the building by constructing

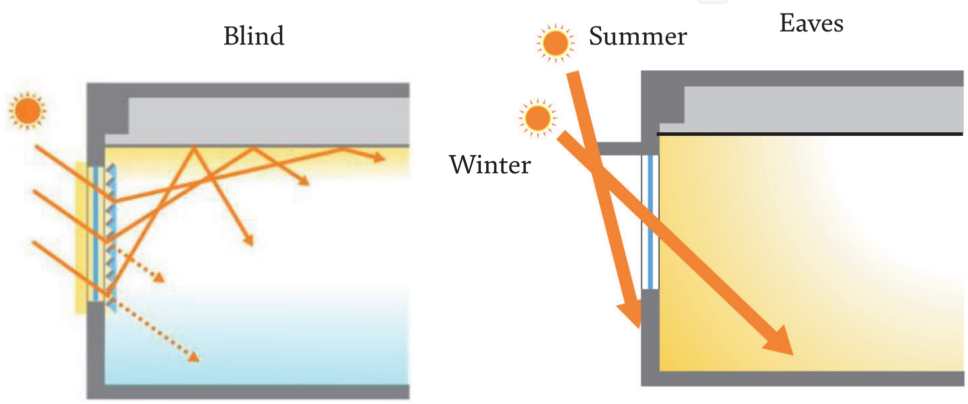

Figure 3.
Specific measures for solar shielding at openings.

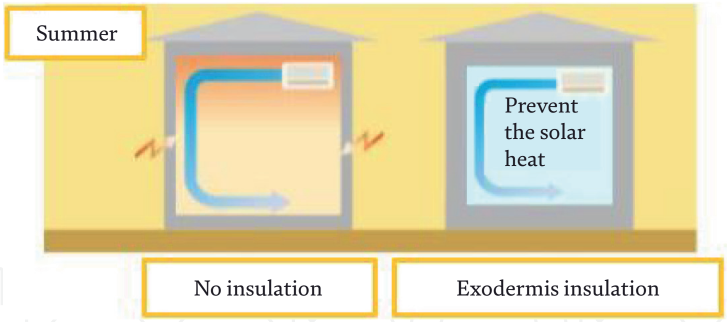

Figure 4.
Image of the effect of insulation in summer.

the exterior skin (roof, walls, floor, etc.). By preventing the penetration of solar heat in summer (**Figure 4**) and the escape of indoor heat in winter (**Figure 5**), energy consumption efficiency for heating and cooling can be improved, and the difference between the surface temperature of the building frame and the room temperature can be reduced, thereby minimizing temperature differences and unevenness in the room.

There are two main types of insulation materials: fiber-based and foam-based, both of which make use of the properties of gases (such as air) that make it difficult to transfer heat. Fiber-based insulation secures heat insulation by retaining air in the gaps between the fine fibers. Foam-based insulation also achieve high-heat insulation properties by trapping air or gases with higher-heat insulation properties inside the bubbles.

Nevertheless, not all regions need to use the same insulation design. A research proposed to optimize the combination of surface reflectivity and the insulation thickness of exterior walls for energy savings in regions of Japan [13]. Calculations of building thermal loads and economic analysis of the total cost for six cities from high-latitude to low-latitude regions of Japan were carried out for a range of surface reflectivity and insulation thickness of exterior walls, and the optimum surface solar reflectivity and insulation thickness for each region were proposed.

Since the openings of a building have the highest heat input and output of the exterior skin, it is important to control the heat input and output by adopting windows with glass that has high thermal insulation performance.

One of the most common types of window glass with high thermal insulation performance is double glazing (as shown in **Figure 6**). In general, double glazing glass has a hollow layer between two panes of glass, which is filled with dry air with

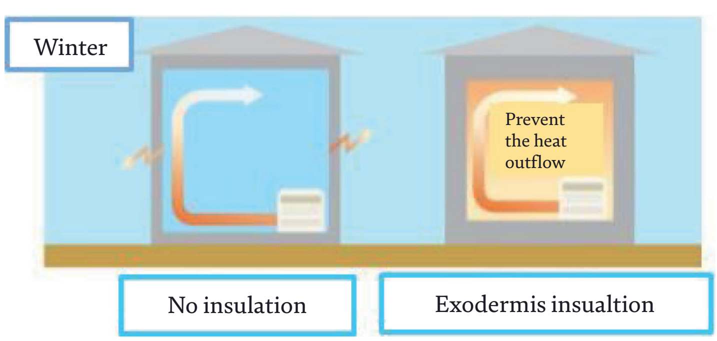

Figure 5.
Image of the effect of insulation in winter.

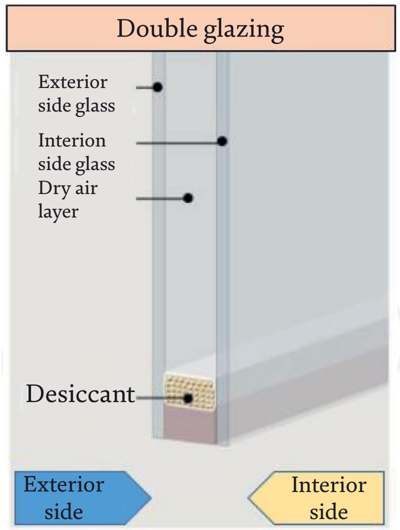

Figure 6.
Common type of double glazing window glass with high thermal insulation performance.

low thermal conductivity or argon or krypton gas with lower thermal conductivity, to improve thermal insulation performance. The thicker the hollow layer, the better the thermal insulation performance, but if the layer exceeds 16 mm, the thermal resistance does not increase due to air convection.

As shown in **Figure 7**, low-E double glazing glass is double glazing glass coated with a special metal film (low-E film) such as tin oxide or silver. This special metal film makes it more difficult for thermal radiation in the hollow layer between the glasses to be transmitted. In summer, solar radiation energy incident on plate glass is reflected outside the room. In winter, it reflects heating heat indoors. As a result, thermal insulation and heat shielding performance can be further enhanced. In summary, by coating the inside of the glass on the indoor side, it is possible to improve the thermal insulation performance to prevent heat from flowing out of the room, and by coating the inside of the glass on the outdoor side, it is possible to improve the thermal barrier performance to prevent solar heat from flowing in.

The thermal transmittance of a single pane of glass is about 5.0 to 6.0 W/m^{2}K, whereas it is about 1.8 to 3.3 W/m^{2}K for double glazing and about 0.76 to 2.6 W/m^{2}K for low-E double glazing.

For this technology, a Japanese study proposed the thermal performance values for conventional windows and low-E windows that include air-flow windows and push-pull windows [14]. The solar heat gain coefficients together with the transmittances, the overall coefficients of heat transfer, and the long-wave radiation factors were presented for conventional windows and the correction values were presented for air-flow windows and push-pull windows. It indicated that the thermal performance of low-E windows was better than that of conventional windows and leads to reduce the thermal load of buildings for the ultimate goal of ZEB.

2.3 Natural daylight utilization

The natural daylight utilization is a technology to reduce energy consumption by bringing in natural daytime light (daylight) through building openings to brighten the room and reduce the use of artificial lighting (or indoor lighting). The energy consumption used for artificial lighting is second only to that used for air-conditioning

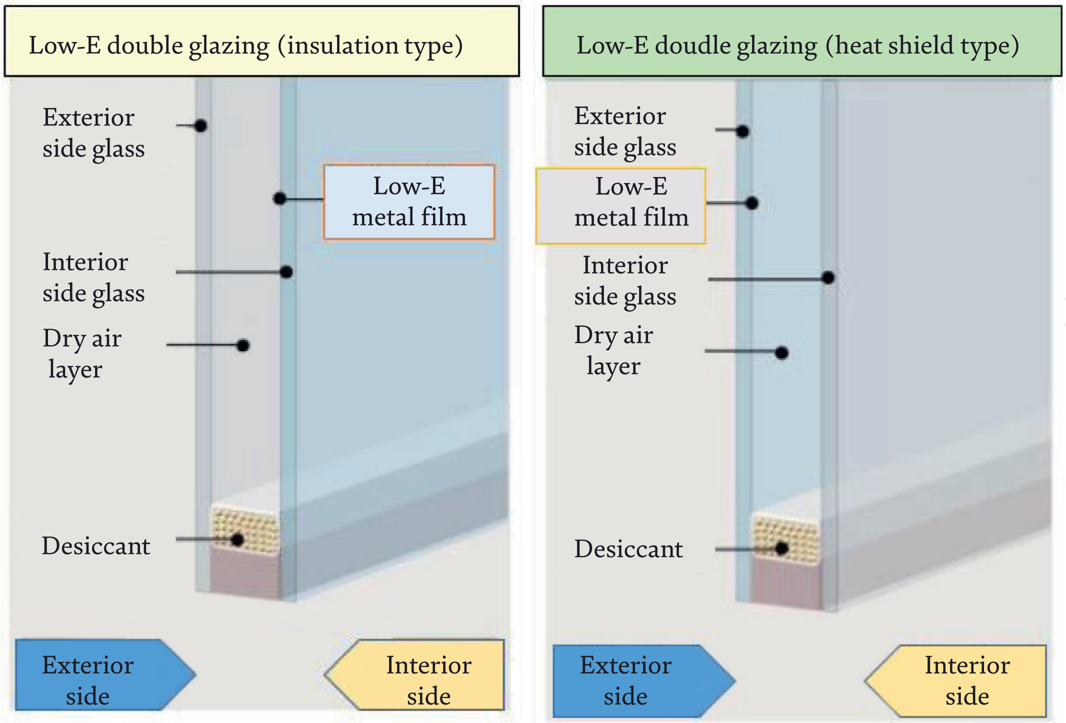

Figure 7.
Low-E double glazing glass coated with a special metal film, the left insulation type is often used in winter and the right heat shield type is often used in summer.

in a typical office building, making it a major source of energy for the building. If daylighting can provide the necessary brightness in a room, energy consumption can be reduced by turning off or dimming the lights to reduce the amount of light, which can also lead to greater energy independence.

As shown in **Figures 8** and **9**, there are two methods of natural lighting: One is to let daylight in directly through the openings of the building to secure the brightness of the room, and the other is to set up a stairwell, a parapet, or reflective eaves to guide the light deeper into the room.

The former (**Figure 8**) is the technique of installing an opening (top light) at the top of a space, etc. For the latter (**Figure 9**), there is a method of installing a "light shelf" in the middle of the window surface of the building to reflect sunlight on the upper surface and bring more light into the interior ceiling to brighten the room. There is also a method called a "light duct system."

Figure 8.
Example of top light utilization in a building.

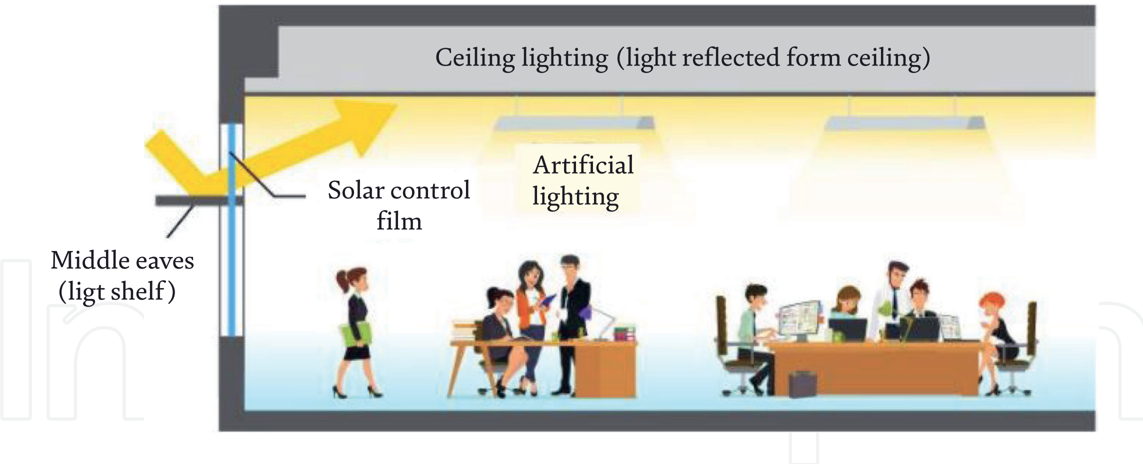

Figure 9.
Example of light shelf utilization in an office building.

For the natural daylight technology, a study reported a verification of an estimation method for daylight and solar radiation introduction by a daylight system [15]. The results showed that the natural daylight utilization is required to have two contradictory functions for energy conservation: reducing lighting energy by introducing daylight and reducing air-conditioning load by shielding from sunlight. In particular, daylight-using facades need to be planned with a balance between the two functions of daylight introduction and solar radiation shielding.

Daylight has the following characteristics: It changes with time, it may bring more brightness than necessary for the indoor visual environment, and it is accompanied by heat. Therefore, when using daylighting, it is important to consider these characteristics and adopt a lighting method that is appropriate for the space characteristics and usage. Without natural lighting suitable for the space characteristics and usage, energy conservation may not be achieved because building users may block daylight, or the energy consumption for cooling may increase more than the reduction in lighting power.

2.4 Natural ventilation

As shown in **Figure 10**, it creates a wind path through the building to enable natural ventilation and natural airflow. This technology is mostly applied to mid-rise offices; however, we can also propose an optimal natural ventilation system for high-rise offices by predicting the wind flow and wind pressure on the exterior walls such as double-skin facade.

Double skin is a system with two skins (glass surfaces) that ventilate the inside of the two skins with outside air. In the summer, the blinds inside the double skin are lowered to shield the building from the sun's rays, and since the sun's rays become heat, the heat is removed by ventilating the building with outside air, thereby reducing the cooling load. In winter, the double-skin ventilation is stopped and the double or triple glazing improves the thermal insulation performance. In the middle of the year, stable natural ventilation is possible through the double skin.

In order to understand the performance of a natural ventilation system that combines solar chimneys and underground pits installed in a university building in Kitakyushu City, Japan, a study conducted a measurement survey over a period of 4 years after the opening of the school [16]. The results indicated that the designed natural ventilation system can greatly reduce the energy consumption of air

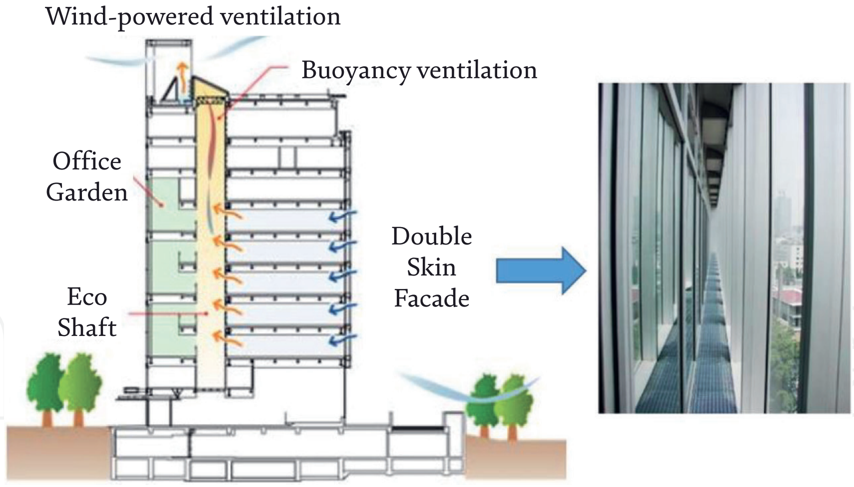

Figure 10.
Example of natural ventilation design in an office building.

conditioning in cooling period, and it can also provide a more comfortable indoor thermal environment.

3. Active technologies

Active technology is a technology for efficient use of energy. It includes high-efficiency lighting, high-efficiency air conditioning, etc. In this section, we briefly introduce these two methods of efficient energy use.

3.1 High-efficiency lighting

In order to reduce lighting energy consumption, it is important to actively use daylighting, for example, by adopting natural lighting techniques. At the same time, it is possible to reduce energy consumption while providing an appropriate lighting environment (illuminance, etc.) by using more efficient lighting equipment such as LED lighting to compensate for the lack of brightness from the use of daylight alone. In addition, by properly controlling such lighting equipment, even higher energy-saving effects can be expected.

Figure 11 shows the examples of lighting control by human sensors and wireless remote thermosat, task-ambient lighting control, and a combination of these controls.

As shown in **Figure 11** on the left, this control uses human sensors to detect the presence or absence of people and turns on or off the air conditioning and lighting. In addition, a remote thermostat that accurately measures the temperature of the area where the person is and efficiently controls the air conditioning.

As shown in **Figure 11** on the right, the ceiling lighting should function as ambient lighting for room ambiance, while desk brightness is adequately provided by the task lighting for work at hand. This is the most effective method for reducing lighting power.

For the high-efficiency lighting utilization in Japan, a study showed that when the high-efficiency lighting fixtures and lighting control systems have been introduced in an office buildings of Japan, the electricity consumption savings of 30 to 50% per year can be expected, and a significant energy savings can be achieved without degrading the quality of lighting [17].

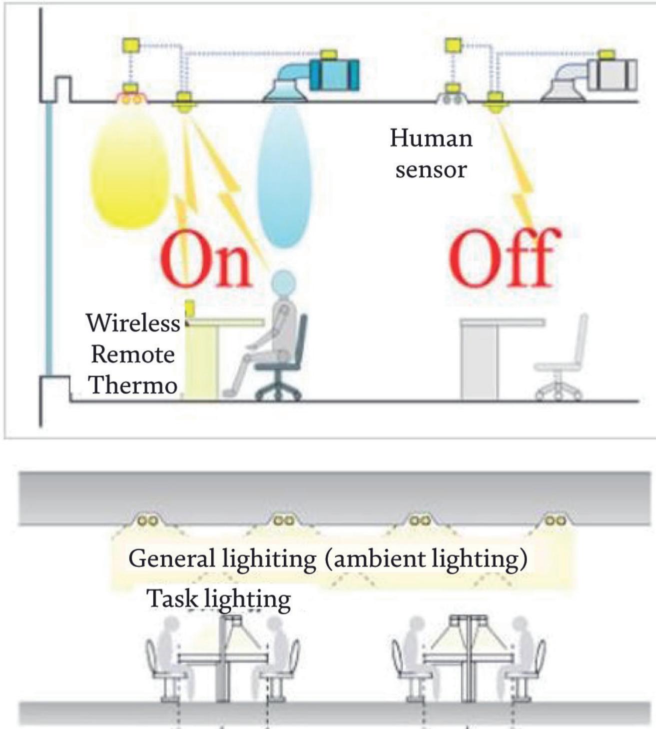

Figure 11.
Example of optimal lighting system control in an office building.

3.2 High-efficiency air conditioning

In order to reduce the energy consumption of air conditioning, it is important to control the load of heating and cooling by adopting passive technologies such as external skin insulation and solar radiation shielding that are elaborated in Section 2. However, since it is often difficult to maintain a comfortable indoor environment with these measures alone, it is important to reduce energy consumption while maintaining a comfortable thermal environment by using an air-conditioning system with higher efficiency and appropriate control to compensate for this. In a typical office building, energy consumption by the air-conditioning system accounts for the largest percentage of the total energy consumption, and the importance of reducing it is very high.

Air-conditioning systems can be broadly divided into central heat source systems and individual distributed heat source systems. In the central heat source system (as shown in **Figure 12**), heat sources are concentrated in machine rooms, etc., and cold and hot water is pumped to the air conditioner for air conditioning. In the individual distributed heat source system (as shown in **Figure 13**), heat sources are distributed and transported using refrigerant piping to air condition for each floor or zone. Both the central heat source system and the individual distributed heat source system consist of “heat source equipment,” “heat transfer equipment,” and “air conditioner equipment”. In the case of a distributed heat source system, the heat source and air-conditioning equipment are integrated into a single unit. Therefore, energy consumption can be reduced by adopting more efficient equipment and implementing appropriate controls for each facility.

In general, the central heat source system is used in large buildings, while the individual distributed heat source system is used in many small buildings.

Measures to reduce the energy consumption of air-conditioning equipment include air-conditioning systems that separate latent heat from sensible heat to adjust

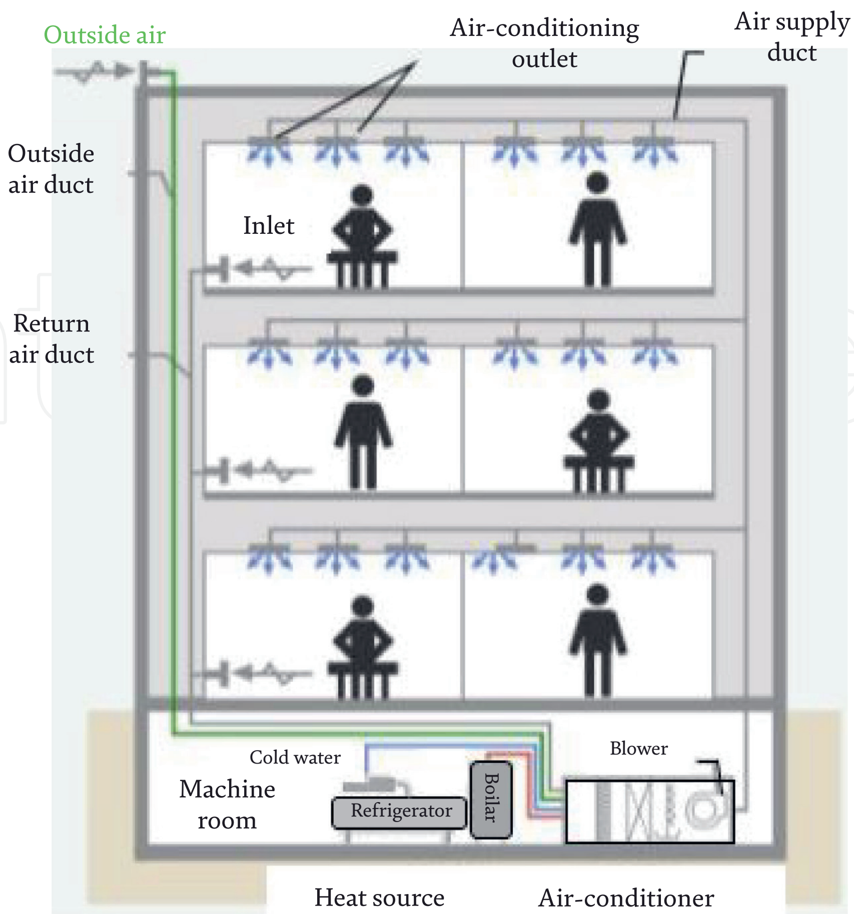

Figure 12.
Example of the central heat source system.

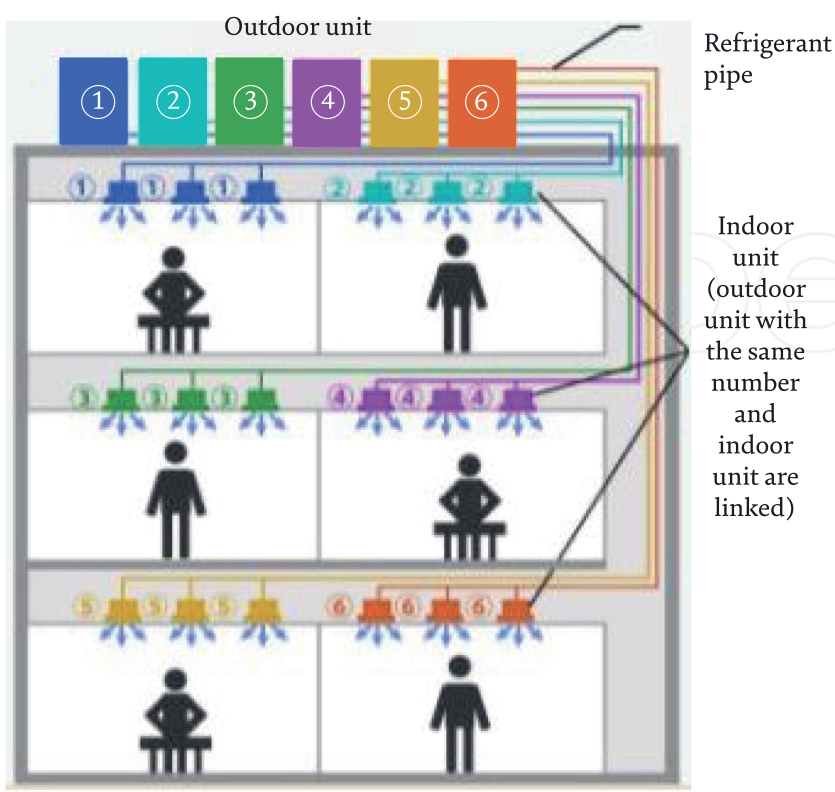

Figure 13.
Example of the individual distributed heat source system.

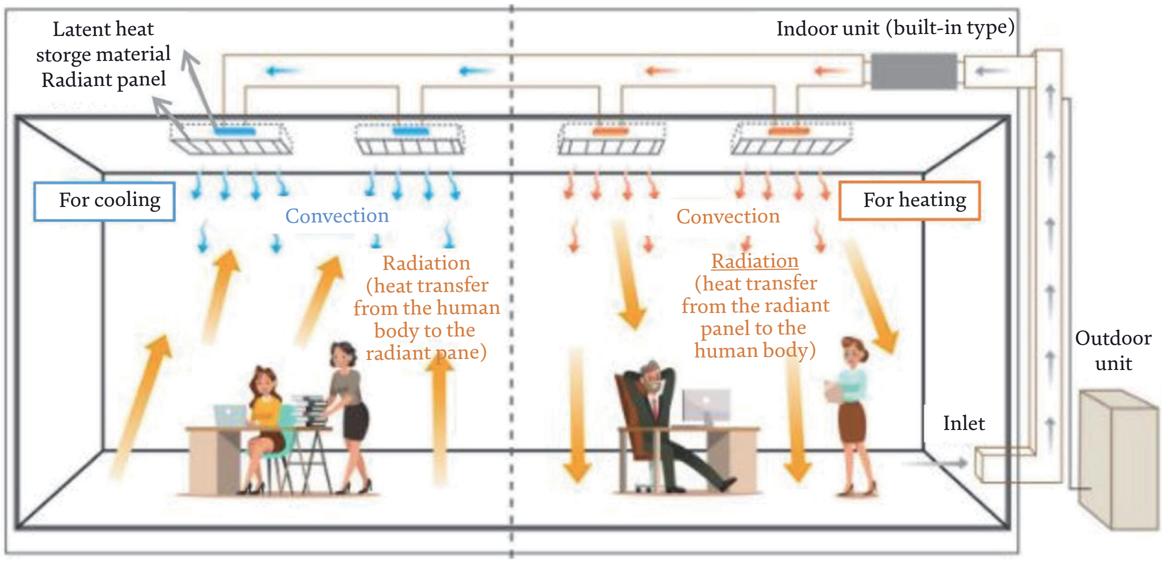

Figure 14.
Conceptual diagram of radiant heating and cooling air-conditioning systems.

temperature and humidity separately, and new air-conditioning systems such as radiant heating and cooling air-conditioning systems (**Figure 14**) that focus not only on temperature and humidity but also on the comfort felt by people.

A radiant heating and cooling system is a system that uses the effect of "radiation (the transfer of heat from a higher to a lower temperature without the use of materials)" to adjust the experience of building users, thereby easing the indoor set temperature and saving energy. Compared to conventional air conditioner systems, this system is more comfortable and less uncomfortable due to airflow drafts and uneven temperatures.

For the high-efficiency air-conditioning system, a study showed that a kind of developed high-efficiency air-conditioning control system with promotion of energy-saving behaviors were installed in may stores of Japan [18]. The "promotion of energy-saving behavior" supports the voluntary establishment of employee behavior by proposing optimal energy-saving behavior for each store based on AI power prediction and displaying screens using nudge theory *via* tablets distributed to stores. The high-efficiency air-conditioning control system suppresses demand based on AI power prediction and operates the air-conditioning compressor at a high COP load rang, and achieves energy savings of more than 3% through behavioral promotion and more than 4% through air-conditioning control.

4. Creation technologies

Creation technology is a technology to use renewable energy to create energy. It includes photovoltaic power generation, biomass power generation, etc. In this section, we briefly introduce these two methods of the creation technologies.

4.1 Photovoltaic power generation

A photovoltaic power generation system generally refers to a power generation system that uses semiconductors to convert light energy from the sun into electrical energy and consists of solar cell modules and arrays, junction boxes and collectors, and power conditioners, as shown in the **Figure 15**.

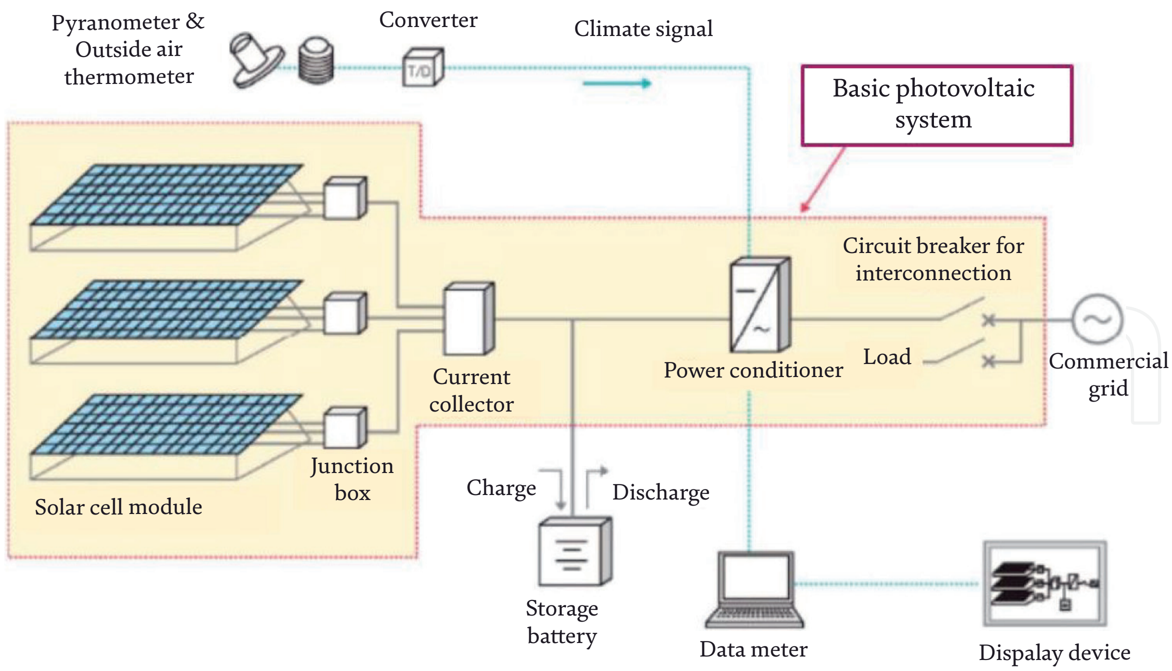

Figure 15.
Conceptual diagram of a photovoltaic power generation system.

The benefits of light energy from the sun are available everywhere, although they vary from region to region, making it the most versatile of all energy creation technologies. When installed on the rooftops of office buildings and commercial facilities, the electricity generated by the photovoltaic power system can be used to meet part of the electricity demand, since the working hours and business hours coincide with the power generation hours. In addition, the system can be promoted as a part of environmental conservation activities, which is a social responsibility of a company, and is beneficial in raising the environmental awareness of employees and securing power in times of disaster.

Particularly in the case of low-rise buildings, the rooftop area is large in relation to the size of the building, and a reasonable amount of power can be expected to be generated in relation to the power demand. On the other hand, in the case of high-rise buildings, since the rooftop area is small compared to the size of the building, the amount of electricity generated by the photovoltaic power system will be small in relation to the electricity demand. Recently, however, there has been progress in the development of "building-integrated photovoltaic systems" that can be installed not only on the rooftops of buildings, but also on walls and windows.

For the situation of photovoltaic power generation in Japan, its research and development and widespread use in Japan began with the oil crisis of the 1970s [19]. At the time, research and development were focused on the use of solar power as an alternative energy source that did not consume petroleum fuel. Later, the movement was further accelerated by global environmental issues and global warming prevention in the 1990s. In the 1990s, the first residential photovoltaic power generation systems were commercialized, and photovoltaic power generation systems evolved from being mainly used for research and development and special purposes to supplying electricity to the general public. In Japan, the feed-in tariff system for renewable energy started in July 2012. In July 2015, the government's Committee on Energy Supply and Demand (CESD) issued a report on the electricity market and presented a supply and demand forecast for various power sources for 2030. In this energy mix, photovoltaic power generation will be responsible for supplying 7% of the electricity demand in 2030.

4.2 Biomass power generation

As shown in **Figure 16**, biomass power generation refers to the technology of generating electricity from biomass (renewable biological resources) such as wood and plant residues. The energy obtained from biomass is also called biomass energy.

When biomass is burned, as with fossil fuels, CO_2 is always generated, but since plants absorb the CO_2 and grow to reproduce biomass, the total amount of CO_2 in the atmosphere does not increase (carbon neutral as shown in **Figure 17**).

By combining this system with photovoltaic power generation, which changes the amount of electricity generated depending on the weather and time of day, it is expected that renewable energy will be supplied in accordance with the demand for electricity.

For the situation of biomass power generation in Japan [20], the Biomass Power Producers Association (BPPA) was established in late 2016, with the aim of addressing the concerns of power producers and promoting the healthy development of biomass power producers. Biomass power generation capacity in Japan reached approximately 3.0 GW by the end of FY2016, approximately 4.0GW by the end of FY2017, and since then, it application has been steadily growing in the years.

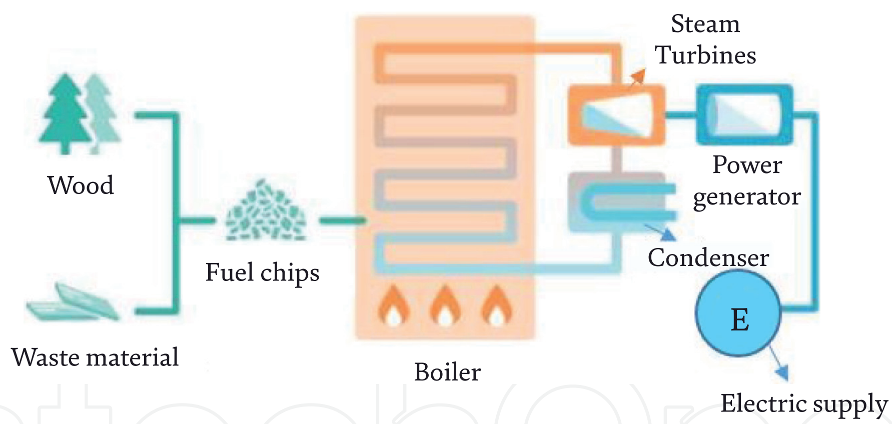

Figure 16.
Conceptual diagram of how biomass power generation works.

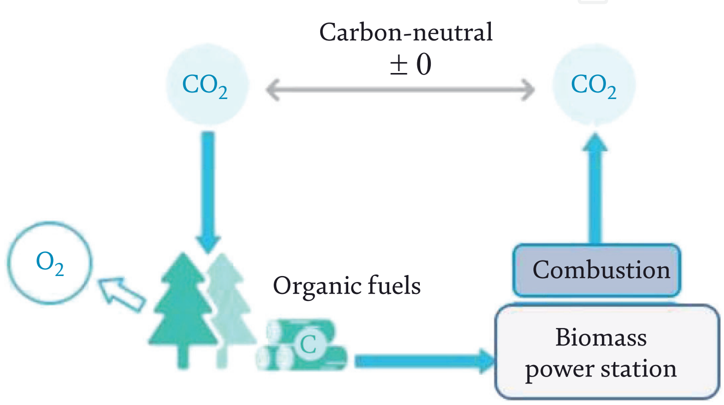

Figure 17.
Carbon neutral of biomass power generation system.

5. Summary and conclusions

This chapter provides an overview of passive, active, and creative energy technologies that are particularly important for realizing ZEB in buildings commonly used in Japan.

The main knowledge obtained in this chapter is summarized as follows:

- Solar shielding technologies that include blinds and eaves installed in the openings can shield the sunlight to enter through windows, and suppress the cooling load in the summer. However, in winter, it is better to take in a considerable amount of solar heat to reduce the heating load by appropriate opening design.

- Exterior skin insulation technologies that include high-performance exterior wall insulation and low-E windows can reduce the amount of energy required to maintain a comfortable indoor temperature compared to a non-insulated building exterior walls and windows by controlling the flow of heat in and out of the building by constructing the exterior skin.

- Natural daylight utilization is required to have two contradictory functions for energy conservation: reducing lighting energy by introducing daylight and reducing air-conditioning load by shielding from sunlight, through proper design of daylight utilization openings.

- A proper natural ventilation system designed in buildings can greatly reduce the energy consumption of air conditioning in the summer cooling period, and it can also provide a more comfortable indoor thermal environment.

- High-efficiency lighting utilization can save the electricity consumption without degrading the quality of lighting.

- High-efficiency air conditioning can reduce energy consumption while maintaining a comfortable thermal environment.

- As a renewable green energy source, the photovoltaic power generation and biomass power generation technologies have been widely applied in Japan and have been steadily growing in the years.

To actually realize ZEB, it is important to consider the following steps: (i) reduce energy demand through passive technology, (ii) use energy without waste through active technology for the demand that is absolutely necessary, and (iii) provide energy through energy creation technology.

Moreover, in the operational phase of a building, it is also important to have energy management technology to determine where energy waste is occurring and how to efficiently operate the facilities. This energy management technology will help reduce energy consumption on an ongoing basis.

Conflict of interest

The authors declare no conflict of interest.

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