

Article

## Zero Emission Buildings in Korea—History, Status Quo, and Future Prospects

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**Abstract:** This paper discusses the history, status quo, and future prospects of Zero Emission Buildings (ZEBs) in the Republic of Korea. The advantages of, and requirements for ZEBs are described, concerning the factors of energy, water, nutrients, and biomass. ZEBs are characterized by net zero energy consumption through the minimization of the energy demand, as well as the onsite production and use of renewable energy. The direct water footprint is reduced by up to 100% through on-site water supply and wastewater management according to the principles of Sustainable Sanitation. The fresh water demand is reduced by using water saving technologies and by recycling of wastewater. Rainwater harvesting, utilization, and infiltration facilitates for onsite drinking water production. Nutrients and biomass from sanitation systems are recycled for local soil application. While traditional Korean buildings can be generally regarded as ZEBs, traditional know-how has been overlooked in the process of modernization and implementation of centralized infrastructure systems in the 20th century. However, the growing interest in sustainability issues in Korea since the beginning of the 21st century is reflected in a growing number of research and development activities, including the design, construction, and operation of ZEBs. The widespread implementation of ZEBs would significantly contribute to sustainable development in the Republic of Korea.

**Keywords:** Korea; Zero Emission Buildings; energy efficiency; energy productivity; renewable energy; sustainable sanitation; rainwater harvesting and management; rainwater utilization; stormwater; urban agriculture

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## 1. Introduction

The sustainable use of resources plays a key role in the global challenge to cope with the extensive resource consumption that exceeds the natural capacity of our planet, and the related environmental, economic, and social impacts. The building sector plays a significant role in this regard, with its portion of global resources consumption at more than 33% [1]. The building sector portion of the total global energy consumption is 40%. Most of the anthropogenic CO<sub>2</sub> emissions result from the burning of fossil fuels [2]. Conventional food production is also responsible for a large portion of the global CO<sub>2</sub> emissions and energy consumption for farming, harvesting, storage, and transport of agricultural products. Furthermore, conventional farming is globally responsible for most of the anthropogenic freshwater consumption [3].

The production of food and drinking water and the management of wastewater are generally decoupled, resulting in environmental pollution and the elimination of resources. In contrast, sustainable infrastructure systems should involve effective, efficient, and integrated local resources management, based on the principles of sustainability and circular flow economies. Centralized infrastructure systems for water management generally include high monetary costs, with the lockup of capital for very long periods; they are also associated with limitations in provision and discharge, and are difficult to adapt to changing demographic structures [4]. In contrast, the decentralization and building integration of infrastructures for the management of energy, water, and organic waste implies many advantages [5–8]. Appropriate decentralized system approaches for efficient supply, use, treatment, recycling, and reuse of resources facilitate the realization of so-called Zero Emission Buildings (ZEBs) [4].

## 2. Method

This paper discusses the development of Zero Emission Buildings (ZEBs) in the Republic of Korea. After outlining a general definition of ZEBs based on specific criteria, traditional and contemporary Korean buildings will be described. An analysis will then be performed to determine the degree to which specific buildings meet the criteria of ZEBs. The emissions from traditional and contemporary buildings are discussed by using qualitative criteria. The analysis of current general building practices, best practice examples for ZEBs, and policy trends regarding the implementation of ZEBs facilitate the formulation of expected future development trends of ZEBs in the Republic of Korea.

The described research is based on the authors' own investigations executed in the framework of an international and interdisciplinary research project on ZEBs. The research uses various sources including personal discussions, field studies, analysis of recent published and unpublished research results, and documentation of best practice examples of ZEBs in Korea. The research project titled, "Zero Emission Buildings, Integrating Sustainable Technologies and Infrastructure Systems (ZEBISTIS)" involved partners from Germany, Republic of Korea, Switzerland, and Turkey, and ran over a period of two years from 2012 to the end of 2014 [9]. The research project is executed in the framework of and supported by the Korean scientific cooperation network with the European Research Area—2012 Joint Call on Green Technologies [10].

The operation of ZEBs should not produce any harmful emissions to the atmosphere, to the water or to the ground. ZEBs should rather have a positive environmental impact as an outcome of the

production of resources, such as renewable energy, freshwater, biomass, and fertile soil. Accordingly, the definition of ZEBs in the ZEBISTIS project and in this paper is much more holistic than the previous definitions of “Zero Emission Buildings”. Those definitions refer generally to emissions from energy generation, and/or to concepts, such as “net zero energy”, “zero net energy”, “net zero carbon” or “equilibrium” [11,12]. The ZEBISTIS project fosters the exchange of the newest developments and compilation of best practice examples. The aim was to accelerate the development of decentralized technologies and infrastructure systems for the sustainable operation of buildings by innovative system configuration. The following sections discuss the history, status quo, and future perspectives of ZEBs in Korea.

### 3. Results and Discussion

#### 3.1. Zero Emission Aspects of Traditional Korean Buildings

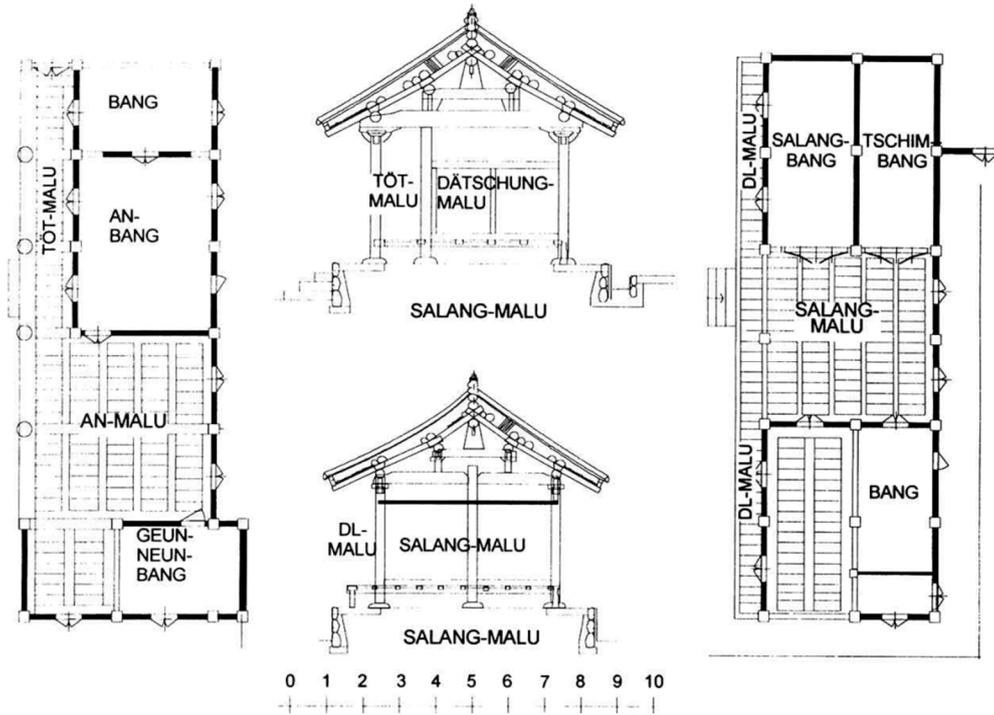
The traditional Korean building type, the so-called “Hanok”, has been adapted over centuries to provide inhabitants with a comfortable indoor climate and to suit the specific temperate climate in Korea; Korea’s climate is characterized by four seasons: a cold and dry winter, a hot and humid summer, and a mild spring and autumn [13].

A family home generally consisted of detached single-story buildings surrounded by a garden and arranged around an unpaved courtyard. Residential buildings in cities represented a compact variation of residential farmhouses. The floor plan layout was generally rectangular or L-shaped. The spatial separation between private property, the road, and neighboring properties consisted generally of walls made of natural stone and/or earth and burnt bricks. The single buildings were accessed via a courtyard, which was connected to the road via a gate in the surrounding wall. Spatially, the courtyard could be regarded as an extension of the interior space of the surrounding buildings [14].

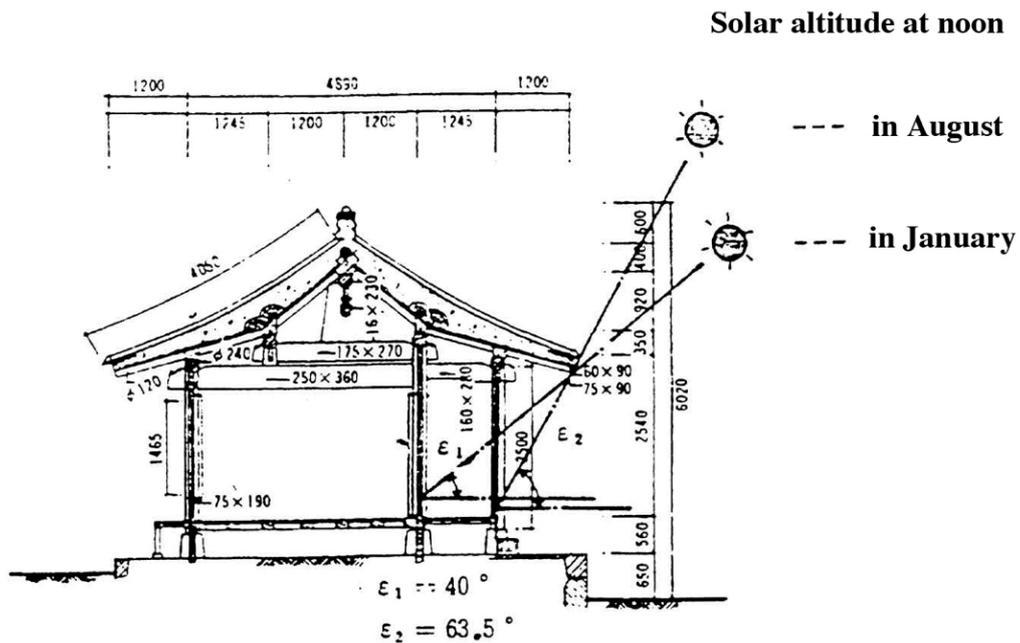
Traditional buildings are built with the regionally available and partly renewable materials of timber, clay, sand, straw, and stone. The entire building is elevated on an architrave block (Figures 1 and 2 [15]) to protect the building from water splashes and ascending moisture. The borders of the architrave block are designed parallel to the eaves and are protected from rainwater by roof overhangs. The buildings have two different floor structures, which are assigned to two different room types. Comparable large and open rooms with well-ventilated timber floors, open ceilings and large windows are called “Malu”. The windows can be opened wide, and are designed to facilitate cross ventilation, passive cooling, and provide a comfortable indoor climate, particularly during the warm seasons. Comparable small rooms equipped with suspended ceilings, small windows, and floor-heating systems (Ondol) are called “Bang”. These rooms are designed to provide a comfortable indoor climate, particularly during the cold seasons (Figure 1 [15]). The room configuration and the design are clearly determined. Variations of the building design are based on modifications of the basic structure [15].

The building structure consists of a timber framework in which the wall surfaces between the vertical timber columns and horizontal beams are closed with translucent or opaque infill materials. Translucent infill generally constitutes openable windows consisting of a timber grid structure, which is covered with mulberry paper. Opaque infill is closed with a meshwork consisting of timber branches or bamboo,

plastered with clay. The roof consists of a heavy multilayered timber roof construction. The roofing consists of straw or burned brick tiles laid on a clay layer [15].



**Figure 1.** Floor plans and sections of traditional Korean residence with specifications of rooms (Bang) designed to provide a comfortable indoor climate during the cold season, equipped with a floor heating system (Ondol) and with living areas designed to provide a comfortable indoor climate during the warm season (Malu), without a heating system and equipped with well-ventilated timber floors and high ceilings [15].



**Figure 2.** Section of a traditional Korean building, with illustration of solar altitudes at noon during summer (August) and winter (January) [15].

Traditional buildings are very well adapted to the Korean climate, providing a comfortable indoor climate with minimal additional technical effort, in contrast to contemporary buildings (Figure 3 [16]). During the hot and humid summer, passive cooling is provided by cross ventilation, shading from a wide projecting roof, and protection from radiant heat by a roof structure with large thermal mass. During the cold and dry winter, the indoor climate can be controlled by opening the windows and using passive heating by direct solar radiation. However, due to the relatively thin walls and windows, the indoor climate cools down rapidly. For the provision of a comfortable warm indoor climate, “Bang” rooms are equipped with a floor heating system, the “Ondol”. The system consists of a fireplace, which is built at one side of the building, and is used as a stove for the preparation of food and hot water. The exhaust gases are led horizontally through a meandering ductwork, situated under the floor of the “Bang” rooms. A chimney is situated on the opposite building side of the fireplace to release the exhaust gases, which are used to heat the floor of the “Bang” room. Both the ductwork and floor are constructed from stone and clay. The floor finish consists of a fine clay layer, laminated with mulberry paper, and varnished with a bean oil coating. The heating systems and stove are fuelled with renewables, such as timber, straw or charcoal. The double function of cooking and heating is only used during the heating period to enhance fuel efficiency and to avoid overheating of the indoors during the non-heating periods [15].



**Figure 3.** Traditional climate responsive Korean building in front of contemporary Korean building in international style with significantly greater heating and cooling demand.

Originally, traditional Korean buildings were not equipped with electrical installations or fresh water supply and sewerage systems. Drinking water was traditionally drawn from natural springs, streams or collectively used groundwater wells, depending on the specific natural basic conditions of a settlement. The water was transported manually to private properties. Therefore, due to the seasonally significant variation in precipitation and changing water availability (the majority of precipitation falls during the summer months), water was used traditionally in a conscious and efficient way. Stormwater, for example, was not directly drained away but was partly collected and utilized on site. Work that required considerably large amounts of water, such as the washing of laundry, was generally carried out alongside surface water bodies, such as streams or rivers (Figure 4 [17]).



**Figure 4.** Washing laundry at a city stream in Seoul in 1890.

Even greywater was traditionally reused, such as for the irrigation of plants. The very small proportion of sealed surface areas had only a very small impact on the natural water cycle. Surplus water is infiltrated and only discharged if the soil of a property or associated public space (street) is completely saturated. Green gardens and courtyard areas in traditional villages and cities serve as small recreational and ecological buffer areas and have a positive influence on the local microclimate. Such areas also facilitated the farming of small vegetable and fruit gardens [15]. The layout of traditional settlements is closely influenced by the specific topography and the location of the natural streams used for the drainage of surplus rainwater, from both natural and built up areas. The roads were generally arranged parallel to streams, while buildings were located on higher elevated ground for protection from pluvial flooding.

Traditional sanitation, organic waste, and farming systems in Korea were closely connected, with zero CO<sub>2</sub> emission. Urine, feces, and organic residue, such as from food production, were not regarded as waste, but were used as precious resources. It was well known that urine and feces could enhance land fertility. The high value of composted excreta for food production is reflected in the old Korean proverb, “You can always give away a bowl of rice, but never a bag of compost” [18]. It was also known that feces needed to be handled in a safe way as it could cause illness. As a consequence, the application of fresh feces was only allowed in early spring or in autumn after the harvest. Until the beginning of the twentieth century, a graded pricing system existed for the marketing of different types of feces collected from households and transported to agricultural areas outside the cities [6]. Various types of toilets were used in cities as well as in rural areas to collect excreta for reuse, with the type of toilet depending on the conditions of each location:

- “Pot-toilets” were mainly used in urban areas. Due to the limited space, the excreta was mixed with ash and collected regularly and carried out of the city to designated sites where it was composted (Figure 5 [19]).

- “Temple toilets” were used in temple areas. These were dehydration toilets, of which the working principle is based on the collection and drying of feces on-site (Figure 5 [19]).
- Pig-toilets were used mainly in rural areas. Human feces were consumed directly followed by defecation by animals (particularly pigs).
- “Ash-toilets” were used in areas with relatively low building density and near agricultural land. The feces were stored and composted on site [3].



**Figure 5.** **Left:** Traditional pot-toilet in Korea; **Right:** Temple-toilet next to houses and agricultural areas.

The ZEB approach discussed in this paper focuses on the operation of buildings and generally does not discuss aspects of emission related to the construction, maintenance, and deconstruction of buildings. However, Korean traditional buildings not only operate sustainably, but are also built and maintained in a sustainable way. The zero emission related design, building construction, and maintenance related concepts of traditional Korean buildings can be assigned to the following aspects.

- The use of environmentally friendly materials with high resource productivity minimizes the total mass and energy flow related to the production of building materials.
- The utilization of local and traditional materials minimizes transportation efforts and allows the preservation of the cultural identity and knowledge in the built environment.
- Renewable materials maximize the carbon dioxide storage.
- Durable components and materials facilitate long-term use and reduce maintenance, renovation, and refurbishment needs during a building’s lifetime.
- Building components and materials can be reused, refurbished, and recycled.
- Multifunctional design extends the utilization-orientated life cycle of a building and facilitates easy conversion, modification or extension for different building uses.
- Maintenance-friendly design, which is well adapted to the local climate and building use, extends the lifetime of the building and its construction materials.
- Deconstruction- and reuse-friendly design enables the extensive, non-destructive deconstruction of the building structure and selected exchange of specific building components.

Accordingly, the construction and operation of traditional Korean buildings and settlements can be regarded as conforming to the concept of ZEBs, and as sustainable according to ecological, economical, and social criteria. However, due to the single-story architecture, the settlement density in Korea is traditionally very low. The growing population and urbanization in the 19th century resulted in the intensive expansion of settlement areas [20,21].

### 3.2. Modern Korean Buildings and Infrastructure Systems—Renunciation from Zero Emission Concepts

During the Japanese occupation of Korea, from 1909 to 1945, modern industrialized materials, buildings, and centralized infrastructure systems of western technology were introduced to Korea. However, the Korean population was still building their houses with traditional materials and in the traditional way. After liberation and the area wide destruction due to the Korean War, most residential buildings in Korea were built according to traditional typologies. However, industrialized materials, such as concrete and burnt bricks, were used to a growing extent. Until 1970, the built up area in Seoul consisted of over 88% single-story buildings with open courtyards. In accordance with the economic growth and development of Korea, particularly in cities such as Seoul, traditional building structures were replaced with multi-story buildings connected to centralized infrastructures. By 1990, the percentage of single story building types of the total building stock had declined to approximately 46% [21] (Figure 6 [22]).



**Figure 6.** Example of area wide urban remodeling area before demolition of existing buildings (**left top and bottom**), and after finalization of new apartment district construction (**right top and bottom**).

Influenced by new urban planning guidelines, the traditional mix of functions in urban neighborhoods was eliminated in urban redevelopment and new development projects. Residential, industrial, and commercial areas were spatially separated. Therefore, the need for mobility and commuting compared with traditional urban developments increased significantly. New high-rise apartment buildings were constructed in the form of cast *in situ* concrete constructions. Contemporary apartments are equipped with centralized floor heating systems powered generally by either gas or electric boilers, to provide a comfortable indoor climate during the cold season. For the provision of a comfortable indoor climate during the warm season, apartments are equipped with air conditioning systems. Until the end of the

1990s, most apartment buildings were of approximately 15 stories, but since the end of the 1990s, buildings have been constructed with 30 stories and over the past 10 years, apartment buildings generally have 45 or more stories. The layout of older low-rise buildings allowed for natural cross ventilation, which could be regarded as a passive cooling measure. Furthermore, the facades of older apartments are equipped with glazed balconies. These spaces serve as thermal buffer zones and static shading elements of secondary facades, which separate the balcony space from the indoor area. Modern high-rise apartments are often attached to a central core equipped with mechanical ventilation and do not facilitate cross ventilation. New apartments generally do not have balconies and have only one façade without exterior shading elements. Accordingly, the architecture of contemporary apartments is generally less adapted to the Korean climate than older apartments or traditional Korean architecture [16].

The current indoor-comfort temperature in Korea of approximately 24 °C requires warmer indoor temperatures during the winter and colder indoor temperatures during the summer. Accordingly, the energy demand for heating and cooling per area unit has generally increased. However, a more compact building design could contribute to lower transmission heat losses. This characteristic is represented by a lower ratio of building envelope to usable area in Korean apartment buildings compared to the smaller single or multifamily houses [13].

Drinking water supply, wastewater, and rainwater management in contemporary South Korean settlements is centralized. Drinking water is generally produced from surface water and supplied to the users via drinking water supply networks. Due to input from urbanized and agricultural areas, surface water must be highly purified before it can meet drinking water quality needs. The drinking water consumption in South Korea is relatively high. The average domestic drinking water consumption in Seoul is 208 liters per person per day, without considering the pipeline losses of the centralized supply network of 8%, and is responsible for 70% of the total urban drinking water consumption [23]. The drinking water consumption in Seoul, for example, exceeds the available renewable water resources significantly. Considering the average rainfall of 1282 mm/year, the total average amount of rainwater landing on the city area would be 775,610,000 m<sup>3</sup>, which equates to only 89% of the standard domestic drinking water demand [24]. In the catchment area of the Han River, where more than 26 million people reside [25], almost 50% of the total yearly average runoff is extracted for freshwater supply of urbanized and agricultural areas. Due to the significant seasonal differences in rainfall, the proportion of extracted fresh water can exceed the natural river discharge [26].

Wastewater in cities is collected via centralized sewer networks and is generally purified in sewage treatment plants. Large apartment complexes are equipped with their own treatment facilities. The treated wastewater is generally discharged in surface water bodies that serve as fresh water reservoirs for domestic, industrial or agricultural water supply [6].

The stormwater from built up areas is generally collected together with wastewater in mixed sewerage systems. During intensive precipitation events, which occur mostly during the summer months, mixed sewage overflows result in significant pollution of surface water bodies. The reason for the discharge of untreated mixed sewage is the limited storage and treatment facilities of the mixed sewage drainage and treatment facilities, which already operate at maximum capacity during dry weather flow [6]. Nutrient rich sewerage sludge is generally disposed of or incinerated [27] or applied, to a limited degree (30% of total), as fertilizer in organic agriculture [6].

Organic and food waste in Korea is generally collected and processed for composting by thermal composting processes. The organic matter can therefore be reused in horticulture and agriculture and therefore partly meets the criteria of a zero emission concept (concerning the reuse of organic carbon). However, the transport and processing of organic food waste with high water content is an energy intensive process that is related to the emissions from the burning of fossil fuels.

### 3.3. Zero Emission Aspects in Korean Development Roadmaps

The building energy consumption contributes to 21% of the total Korean energy consumption, and is expected to increase to 40% by 2030 [28]. In order to lower the total energy consumption and greenhouse gas emissions, it is therefore necessary to improve the energy efficiency of buildings in Korea.

According to the Korean energy roadmap, the energy efficiency of new buildings needs to be improved during the period of 2012 to 2025. From 2025, residential buildings must have net zero energy consumption and non-residential buildings should have an energy saving rate of 60% (see Table 1 [28,29]).

**Table 1.** Development of energy saving rates and exemplary measures of new building constructions in the Republic of Korea according to the national energy roadmap.

Year	2009	2012	2017	2025
Building energy efficiency category	Energy intensive house	Low energy house	Passive house	Zero energy house
Energy saving rate residential buildings	0%	30%	60%	100%
Energy saving rate non-residential buildings	0%	15%	30%	60%
Specific reduction factors	0% reduction of heating and cooling energy demand	50% reduction of heating and cooling energy demand	90% reduction of heating and cooling energy demand	90% reduction of heating and cooling energy demand
Applied improvement measures (building envelope and services engineering system)	7 cm thermal insulation, double glazing, high efficiency boiler	15 cm thermal insulation, triple glazing, mechanical ventilation with heat recovery	25 cm thermal insulation, high efficiency windows, LED lighting	25 cm thermal insulation, high efficiency windows, LED lighting, renewable energy production

The national plan is to optimize the energy efficiency and productivity of Korean buildings with multiple measures defined in the so-called “Building Energy Efficiency Program” (BEEP). Specific target values for the energy efficiency of different building types will be defined in the building code and be part of the construction permit conditions. Furthermore, separate design criteria for “construction”, “machinery”, “electric facilities”, and “renewable energy” are described in the building code. A building energy efficiency rating certification system for newly built or renovated apartment and office buildings

is also part of the BEEP. The energy efficiency of specific buildings will be assigned to 5 different grades, from 1 (most energy efficient) to 5 (least energy efficient), based on the simulation of primary energy performance. The system was introduced voluntarily in 2001. In the 10-year period up to 2011, a relatively small number of buildings have been evaluated. Because of the voluntary character of the rating systems, only 541 apartment complexes and 201 office buildings were graded. Another part of the BEEP is a management system for Greenhouse Gases (GHG) and Energy Targets (ET). The participation in the program is compulsory for owners of buildings that emit more than 25,000 tons of CO<sub>2</sub> per year [28].

The Korean building energy policy envisions the realization of a low carbon, green society by expanding the green building sector. The goal is to reduce the GHG emissions of the building sector by 27%–31% by 2020. The strategy to achieve this goal involves the following key points:

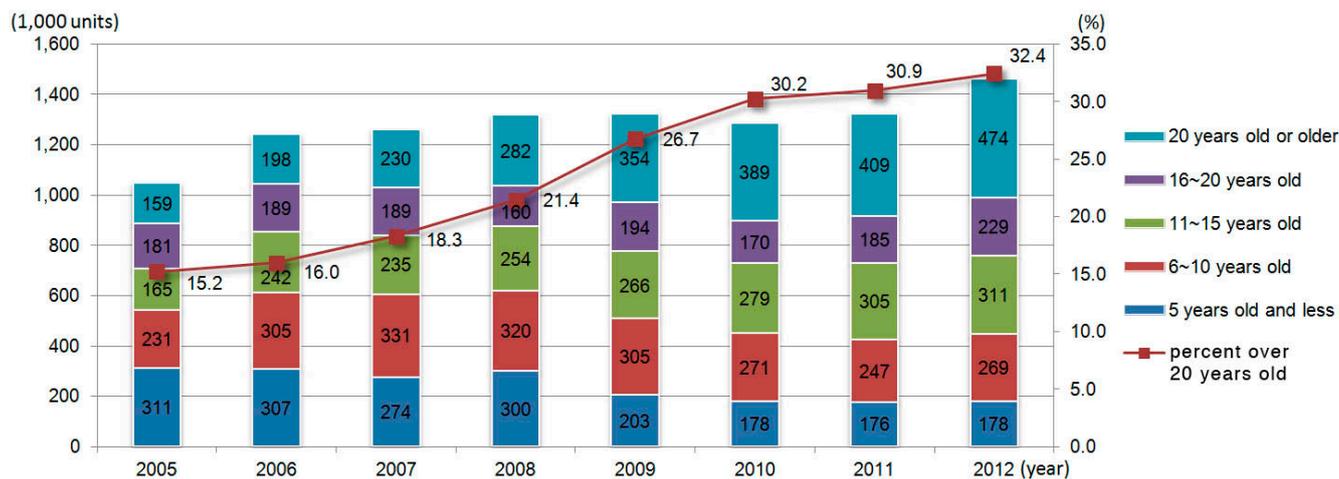
- (1) Strengthening of building energy regulations and standards
- (2) Improvement of energy efficiency of existing buildings
- (3) Encouragement of building users' energy conscious behavior
- (4) Development of green building technologies and infrastructure systems.

The aim of strengthening both building energy regulations and standards is to reduce the heating and cooling energy demand of buildings. For example, the maximum u-values for windows and doors have already been minimized. The upper limits have been reduced from 3.84 W/m<sup>2</sup>K in 2001 to 3.0 W/m<sup>2</sup>K in 2008, to 2.4 W/m<sup>2</sup>K in 2010, and to 1.5 W/m<sup>2</sup>K since 2012. Furthermore, the installation of items for the reduction of the cooling energy load, standby power programs, LED lighting, and highly energy efficient appliances need to become compulsory. In the future, building permit systems should be based on the evaluation of a building's energy demand, and should require net zero energy performance for all new buildings in the Republic of Korea. However, to achieve the goal of such a significant reduction of the overall energy consumption of the building sector, not only new buildings but also the energy efficiency optimization of the existing building stock needs to be addressed.

The average expected lifetime of residential buildings in Korea is only 20 years [30], which is a very short period compared to Japan (30 years [30,31]), Germany (79 years [30]), France (85 years [30]), USA (55 [31]–103 years [30]), and UK (77 [31]–140 years [30]). In 2002, more than 44% of the residential building stock older than 22 years were apartments [30]. In 2014, approximately 60% of the South Korean population lived in apartment buildings [32]. Apartment buildings are being developed with increasing density and in direct neighborhoods of districts with low-rise multi and single-family houses. Drivers for developments with increasing building heights and densities are primarily economical aspects, such as the aim to increase value enhancement by the reduction of land consumption in relation to useful built up area [21,33].

The number of aged apartments is rapidly increasing and it is expected that in the future, the demolition and reconstruction of apartments will become more difficult due to decreased business potentials, caused by the slump in the real estate business. If the real estate values do not significantly increase, the costs for demolition and construction of new apartments will exceed the profits that can be achieved by selling. This trend is reflected in the fact that the portion of apartments with an age of more than 20 years in relation to the total apartment stock increased from 15.2% in 2005 to 32.4% in 2012 (see Figure 7 [32]). The total number of apartments older than 21 years in 2012 was 1.691 million.

Massive construction of apartments was realized in the 1980s and a growing portion of buildings constructed in that period are now reaching more than 30 years old [32]. Such apartments are generally in need of full renovation but continue to be habitable into the future. Accordingly, the development of systematic maintenance policies for aged apartments is inevitable for sustainable development, particularly in order to extend the buildings' lifetime, to improve the energy efficiency [32], to reduce hazardous emissions, and improve living quality.



**Figure 7.** Development of the apartment building stock in the Republic of Korea, from 2005 to 2012 (in apartment units and percentage of total).

The improvement of the energy efficiency of existing buildings is addressed by Korean policy through the promotion of the public sector's voluntary labeling of annual energy use, CO<sub>2</sub> emissions, and facility performance of buildings when they are rented or sold. Incentives for the participation in energy efficiency and green building certifications include tax reduction or relaxation from building standards (such as increase of floor area ratio limitations). One million existing homes, with a focus on social housing, will be "greened" from 2010 to 2018. One third of old buildings need to be remodeled, addressing the need for the improvement of energy efficiency, supported by policy funded favorable loans.

The building energy sector in the Republic of Korea provides a clear roadmap for the reduction of emissions related to the provision of energy. In contrast, visions, plans or roadmaps for the reduction of building emissions related to the sectors of water, nutrients, and organic waste have not been officially defined. A measure for the optimization of infrastructure systems for water supply and wastewater treatment generally focuses on leakage control. Optimization measures also address the enhancement of drainage, retention, and treatment capacities of a centralized infrastructure system. Decentralized measures for diffuse stormwater pollution control by the so-called Low Impact Development (LID) and flood control by decentralized retention and management of rain- and stormwater are discussed to a growing extent. Many products and systems for the realization of LIDs are already available on the Korean market. However, an area wide application is not yet supported by policies, such as compulsory regulations or provision of incentives. Nevertheless, the important role of integrating more green areas for recreational and ecological purposes is addressed in several initiatives. The Seoul Metropolitan Government for example addresses the lack of green spaces in the city. The aim is to create easily

accessible green parks in urban areas of Seoul, where more than 80% of green areas are concentrated in suburban areas in the form of mountain forests [34].

Existing regulations focus primarily on the reduction of drinking water consumption, e.g., by rainwater management harvesting and utilization and/or the recycling of wastewater. To reduce the urban drinking water consumption, the national water act of South Korea requires hotels, shopping malls, and industries exceeding a specific water consumption to recycle wastewater on site for non-drinking purposes, e.g., irrigation and toilet flushing. Provided incentives include investment cost subsidies and tax reductions [35].

A more sustainable management of nutrients and organic wastes from urban areas has not yet been addressed in the regulations or supported by specific incentive systems. The development of new and innovative systems is therefore primarily driven by marketing concepts and ideas to create demands for new products. An example of the decentralized collection, transport, and thermal composting of organic waste from residential buildings, a decentralized thermal fermentation and dehydration system, is the so-called Zero Food Waste System (ZFWS). In the ZFWS, food waste is mixed with wood chips that need to be transported to the treatment site. The food waste is thermally composted together with wood chips in order to reduce the humidity of the resulting composted product. Prototypes have a treatment capacity of 50 kg food waste per day and have an expected electric energy consumption of 10 KWh/day (200 Wh/kg food waste). The food waste needs to be mixed 1/1 with wood chips [36], which must be produced and transported to the decentralized treatment site. Accordingly, the transport effort for the wood-chips involved in the energy intensive onsite treatment process is similar to the conventional transport of decentralized collected organic food waste to a centralized composting site for the production of soil supplement. The resulting product from the ZFWS systems can be used as a soil supplement or combusted. However, considering the electricity consumption of the decentralized treatment system, and the need for the production and transport of wood chips, it is questionable whether the ZFWS meets the criteria for a zero emission concept.

A comprehensive approach for addressing the reduction of emissions in the South Korean building sector is not reflected in either current policies or regulations. However, public and private sectors have invested a great deal of effort to develop and realize sustainable buildings. Some of the sustainable buildings that have been realized in the Republic of Korea also meet the zero emission building criteria described in this paper. The following section discusses selected examples of such Zero Emission Buildings in the Republic of Korea.

### *3.4. Examples of Zero Emission Buildings in Korea*

Worldwide, several hundred completed buildings address the need for net zero energy consumption. More than 300 buildings, most of them located in Europe, were already identified in 2010 [37]. Such buildings are also defined as zero emission buildings, but refer to net zero carbon dioxide emissions related to the operation of net zero energy buildings [11] only, and do not address other emissions. In the framework of the ZEBISTIS research project, identifying realized examples of contemporary ZEBs that meet the comprehensive approach and definition of ZEBs was challenging. The operation should not produce any harmful emissions to the atmosphere, water or ground, but should have positive

environmental impacts due to the production of resources, such as renewable energy, fresh water, biomass, and fertile soil.

For the identification of potential ZEBs, an assessment system was developed [38,39] that considers the quantification and evaluation of resource flows within the system boundary defined by the physical boundary of a building site (property). The specific resource flows can be determined on building design documents and/or post-occupancy performance data.

With the “ecological scarcity method”, ecological impacts of emissions to air, surface waters, groundwater, and soil as well as the consumption of resources and the production of wastes can be measured, evaluated, and weighted with “eco-points” [40]. The required life cycle assessment data for the calculation of eco points for selected ZEBs has been mainly retrieved from the KBOB (Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren) list [41] and the Ecoinvent database [42], and have been supplemented with specific calculation for parameters that have not been available in any databases [38,39].

Based on a literature survey, buildings that could potentially serve as ZEB case studies were selected. An analysis was performed on the degree to which the sectors’ biomass, energy, and water were addressed in the zero emission concepts of the selected buildings. Only buildings that addressed at least two eligible processes of at least two of the three sectors, biomass, energy, and water, were considered to address sectors and processes sufficiently (Table 2 [38,39]) according to the ZEB concept. For the evaluation of potential ZEBs, an additional sector for qualitative and superior aspects has also been created (Table 2) [38,39].

**Table 2.** Sectors, eligible processes, and assessment units for the selection of ZEB (Zero Emission Building) case studies and the calculation of eco-points.

Sector (Eco-Point Assessment Units)	Eligible Processes (At Least 2 Processes Have to be Addressed by ZEBs in 2 of the First 3 Sectors)
<b>Biomass</b> (Yes/No)	<ul style="list-style-type: none"> <li>• Composting of organic waste</li> <li>• Composting of feces</li> <li>• Nutrient recovery from urine</li> <li>• Food production</li> <li>• Aquaponic production system</li> <li>• Production of fertile soil</li> </ul>
<b>Energy</b> (kWh/a, MJ/a)	<ul style="list-style-type: none"> <li>• Photovoltaic generators</li> <li>• Solar thermal collectors</li> <li>• Wind turbines</li> <li>• Geothermal energy use</li> <li>• Highly insulated building envelope</li> <li>• Passive solar energy use</li> <li>• Heat recovery</li> <li>• Use of waste heat</li> </ul>
<b>Water</b> (m <sup>3</sup> /a)	<ul style="list-style-type: none"> <li>• Rainwater harvesting</li> <li>• Water saving devices</li> <li>• Decentralized wastewater treatment</li> <li>• Reuse of water</li> <li>• Urine separation</li> </ul>

Table 2. Cont.

Sector (Eco-Point Assessment Units)	Eligible Processes (At Least 2 Processes Have to be Addressed by ZEBs in 2 of the First 3 Sectors)
<b>Qualitative and superior aspects</b> (Applies fully, partly or not)	<ul style="list-style-type: none"> <li>• Good connection to public transport</li> <li>• Integration of greenery on roof and in façade</li> <li>• Building construction is easily adaptable to different building uses</li> <li>• Building is constructed with environmental friendly materials</li> <li>• Low grey energy content of building construction</li> <li>• Building design fits to the surrounding environment</li> </ul>

As a result, the Kolon e+ Green Home in the Republic of Korea has been identified to fulfill the previously defined ZEB criteria sufficiently. According to the evaluation results, the Kolon e+ Green Home has a quite balanced approach to the addressed zero emission sectors biomass, energy, water, and additional qualitative and superior aspects. The building also has a very low impact on the environment (expressed by a low number of eco-points and a high degree of ZEB achievement). The proportion of each sector's eco-points in relation to the total number of achieved eco-points (100%) is expressed in percentages (Table 3, [38]). Subsequently, the zero emission concept of the Kolon e+ Green Home is discussed in more detail.

**Table 3.** Overview of the ecological impact of Kolon e+ Green Home with information regarding the proportional contribution of specific zero emission sectors to emission reduction.

<i>Case Study—Building Name</i>	<b>Kolon e+ Green Home</b>
<i>Country</i>	Korea
<i>Building type</i>	Single-family house
<i>Degree of ZEB achievement</i>	94%
Proportion contribution to eco-point calculation divided by sectors:	
<i>Eco-points/m<sup>2</sup></i>	12
<i>Biomass</i>	25%
<i>Energy</i>	10%
<i>Water</i>	52%
<i>Additional</i>	13%
<i>Total</i>	100%

#### 3.4.1. Kolon e+ Green Home

The Kolon e+ Green Home is a detached single-family house that has been constructed by the Kolon Institute of Technology with the strategic partners of Unsangdong Architects Corporation, Korean Institute for Construction Technology (KICT), Fraunhofer Institute for Solar Energy (ISE), Hanil Mec.Elec. Consultants, and CVnet Corporation. Six build partners and 29 supply partners were involved in the design, planning and construction, and operation and monitoring processes of the building. The building was finalized in 2010 and is located in Kyeong Gi on the property of the Kolon headquarters (Figure 8). In recent years, the building was operated and monitored, though it was not occupied by building users for the first few years. Therefore, the influence of occupants needed to be considered by adjusting the monitoring results, e.g., based on experiences in other buildings. In 2014, the building was

occupied by a household for a limited period and utilized in order to validate the monitoring results and calculation from the previous years [43]. Kolon e+ Green Home is not continuously occupied because it is generally open for visitors. The building serves as both sustainable building case study and exhibition space for sustainable technologies.

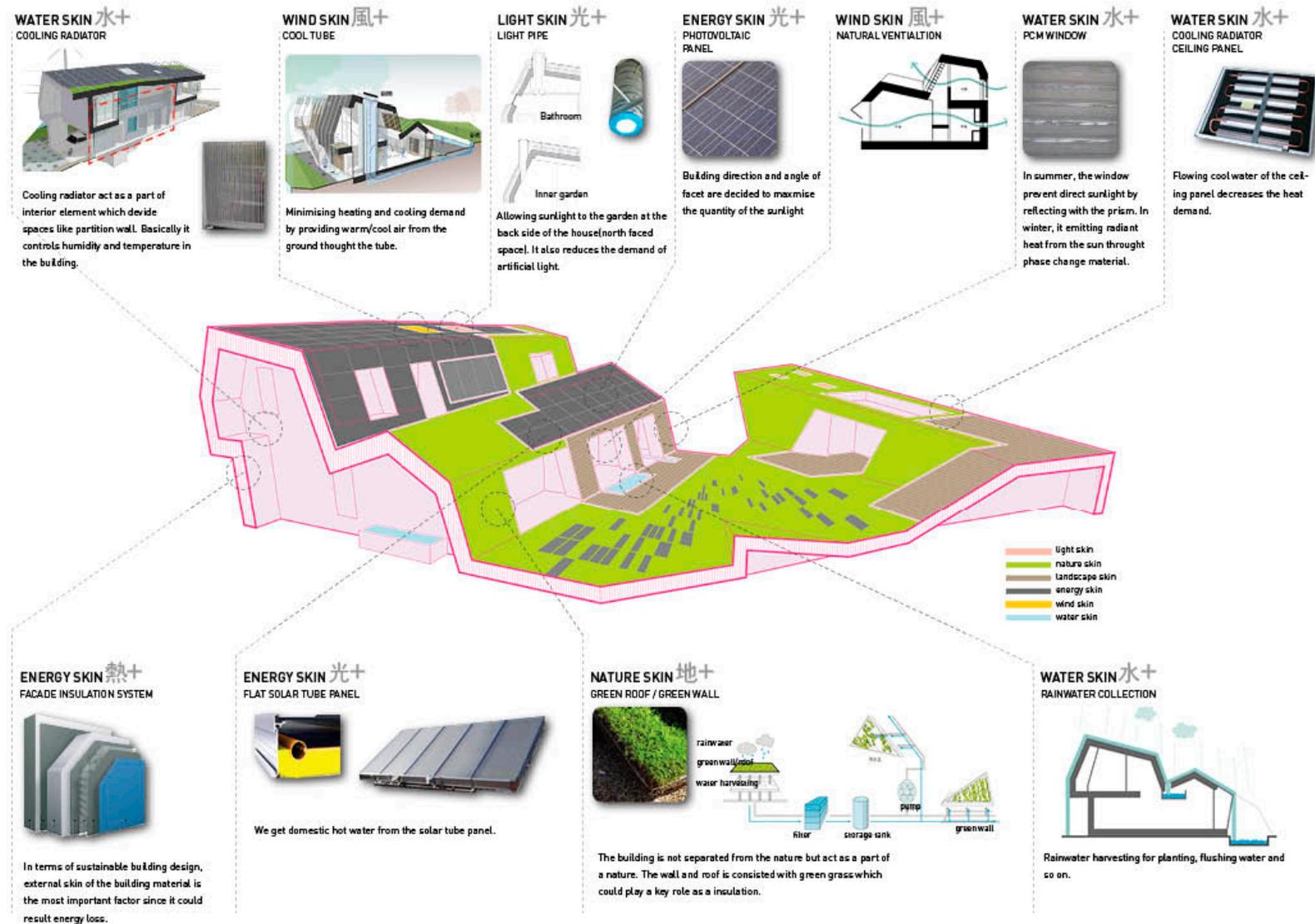


**Figure 8.** Aerial view of Kolon e+ Green Home by Sergio Pirrone [44]. The view clearly shows the green roof, facades, roof-integrated PV generators, and solar thermal collectors. The Kolon headquarters building is visible in the background, left.

Kolon e+ Green Home is very energy efficient, and is certified as a Passive House by the German Passive House Institute. The electric energy consumption is 531 kWh/a and the building's useful area is 295 m<sup>2</sup>. Accordingly, the electric energy consumption is only 1.82 kWh/m<sup>2</sup>a. The building is connected to the public electricity grid and does not store electric energy. The building can therefore be defined as a low energy or nearly net zero energy building. The building is equipped with 95 different green technologies, which contribute to the energy, water, and resource efficiency of the building and aim for the provision of a comfortable and healthy indoor climate. An overview of the location and function of selected features is provided in Figure 9 [44].

Mitigation of heat island effects, evaporation of water, and passive cooling, as well as the retention of rainwater are increased by extensive greening of some of the building's roof and façade surfaces. To reduce drinking water consumption, the building is equipped with water saving appliances and fixtures, such as faucets, showerheads, toilets, rainwater harvesting and utilization, and a greywater recycling system. For the building construction, the utilization of ecological materials has been addressed. However, nutrient and biomass aspects have not been fully addressed in the building project [43].

According to the ZEB assessment system [38] developed in the ZBISTIS project [9], the Korean buildings presented subsequently could also be defined as ZEBs. They address multiple aspects that are required for classification as ZEBs. However, the quantification of building performance is not feasible in this study. Either the buildings do not operate according to their appointed building use, or no data for the quantification of the building performance was available during the writing of this paper.



**Figure 9.** Isometric drawing of Kolon e+ Green Home with location and brief description of measure contributing to the building's energy and water efficiency.

### 3.4.2. Samsung Green Tomorrow

Samsung Green Tomorrow is a single-family house, owned by Samsung C&T Corporation. It was designed and built by Samsung in collaboration with Samoo Architects and Ove Arup & Partners. It is located in Gyeonggi-Do and has a use area of 423 m<sup>2</sup>. Sixty-six green features are addressed and it is the first project in East Asia to achieve the LEED Platinum award. Samsung also plans to apply the green concepts utilized in Green Tomorrow to its residential construction projects in order to cut the building's energy consumption and improve sustainability [45]. However, the building is not used according to its purpose as a residential building, and serves primarily as a showcase for cutting edge technologies and design ideas that facilitate the realization of sustainable buildings. The single story design with very low density and a relatively large living area for one family suggests this building is not intended to be a model home for the majority of the Korean population, but a luxurious and outstanding example of a green building. The general building concept (ecological materials, net zero energy consumption, and reduced water footprint by rainwater harvesting management and utilization and greywater recycling) is basically comparable to the Kolon e+ Green Home. However, the concept of the Samsung Green Tomorrow building involves electric energy storage and connection to electric cars.

### 3.4.3. Daelim Greenhome Plus

The first pilot project for sustainable high-rise apartments in South Korea, "Greenhome Plus" was built between 2006 and 2010 in Songdo, a newly developed district, on reclaimed land in the coastal area of the city of Incheon. The building was developed by the Daelim Company in cooperation with the Yonsei University and approximately 30 other organizations. In Greenhome Plus, "green" building concepts and technologies are applied that are comparable with those at the Kolon e+ Green Home, but adapted to a building typology suitable for high-rise apartment buildings. Different experimental houses have been constructed for Greenhome Plus, with energy saving rates of 40%, 60%, and 80% in comparison with standard apartments, and zero energy houses.

Nutrient and biomass aspects are not addressed in the Greenhome Plus building project. The building uses water saving technologies and combines rainwater harvesting and management with a greywater recycling system. The heating and cooling energy demand are reduced by external thermal insulation, double windows with external blinds and heat absorption glazing, mechanical ventilation systems with heat recovery, and low temperature radiant heating and cooling systems. The required heating and cooling energy demand is provided by water-to-water heat pumps using low temperature geothermal energy. Renewable electricity is produced with roof and facade integrated PV panels. Facade integrated vacuum tube collectors support warm water production and heating systems. Roof surface areas that are not equipped with PV generators are extensively and intensively landscaped as greened roofs (Figure 10 [46]).



**Figure 10.** Isometric view of Greenhome Plus with indication of the main building integrated features for greening, water and energy management, and renewable energy production.

#### 3.4.4. Non-Residential Buildings and Future Prospects of Zero Emission Buildings in Korea

In addition to the buildings discussed above, other non-residential buildings addressing zero emission aspects such as energy efficiency and productivity measures can be found in the following references: “Climate Change Research Center” in Incheon [47], “Energy Dream Center” in Seoul [47], “Post Office Seonam” in Sampyeong [48], and “Zero Carbon Green Home” in Ilsan [49].

The presented case studies of sustainable building projects illustrate that zero emission buildings can be principally realized in the Republic of Korea. However, most built examples, addressing multiple zero emission criteria, are not yet operable under actual conditions and function as case studies for further research and development. Furthermore, the single-family houses presented are not representative of the Korean Housing market, which mainly comprises multi-family and apartment buildings. However, the examples of ZEBs in Korea discussed in this section illustrate the feasibility to transfer zero emission concepts of traditional Korean buildings to contemporary architecture. According to the example of Greenhome Plus [46], ZEBs can also be realized in settlements with comparable high building densities and are therefore compatible with the majority of Korean housing estates. Furthermore ZEBs provide generally higher indoor and outdoor comfort levels and healthier living environments compared with conventional buildings. It can therefore be expected that ZEBs would be very well accepted by dwellers.

Building companies currently regard the further development of energy efficient and resource productive buildings as not economically attractive or feasible. An important reason is the comparable low consumer prices, e.g., for energy and water, and a lack of compulsory requirements, such as energy performance certificates and building codes, which aim for higher energy and resource efficiency. Obviously, while cost savings are achievable with the reduction of operation costs, through the realization of energy efficient and resource productive buildings and improvement in living quality, they do not

facilitate the development of profitable zero emission business models for construction companies and real-estate developers.

#### **4. Conclusions**

Based on the findings presented in this paper, it can be concluded that Korea has a long history of sustainable living and the construction and operation of zero emission buildings. However, during the 20th century, much of the traditional building knowledge and practice has been overlooked. Rapid modernization and development processes in Korea have resulted in the area-wide adaptation of international standards in urban development and architecture. Such standards generally do not meet zero emission criteria. Since the beginning of the 21st century, a growing interest in green and sustainable development has been observed in Korea. Recent research and development projects carried out by public and private actors address the reduction of resource consumption and emissions to the environment. Comparable with international trends, the primary focus of zero emission concepts in Korea is the combustion of fossil fuels and related CO<sub>2</sub> emissions. Accordingly, strategies to increase energy efficiency and production of renewable energy in order to reduce GHG emissions are of particular concern. The second important issue addressed is the reduction of water consumption by the use of water saving appliances, the recycling of wastewater, as well as rainwater harvesting, utilization, and management. The latter is also related to the retention of stormwater and is therefore also important for flood control, the avoidance of damages in urban infrastructure, and adaptation of the effects of climate change. The densification of cities in order to accommodate an increasing population and to avoid vast urban sprawl and transportation needs is widely accepted as a sustainable urban development strategy. However, green spaces are of vital importance for high living quality [50], and play an important role in the accommodation of sustainable infrastructure systems based on the principles of a circular flow economy involving the effective and local management and production of renewable resources, such as organic wastes, water, and food. The densification of urban environments reduces the available land area for urban green spaces within such urban developments. Accordingly, and analogous to the concept of an edificial densification, both concepts need to be developed for the densification of urban green spaces and the provision of more green spaces in built up urban areas. For example, urban green spaces of housing developments could be re-interpreted as multifunctional productive garden rooms to provide better living quality and increased well-being for the urban population, and the accommodation of nature orientated and ecologically sound urban infrastructure systems.

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#### **Conflicts of Interest**

The author declares no conflict of interest.

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