

Current Actuality of Sustainable Architecture: Prospects, Obstacles and Practical Implementation Strategies

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Abstract. Conventional architecture requires a lot of energy and emits a considerable amount of carbon dioxide, not only during its construction but also in the use process. According to the report released by the China Association of Energy Building Efficiency in 2020, the overall energy consumption of architecture takes up 46.5% of the final energy consumption in China. As environmental issues become one of the most important affairs worldwide, conventional architecture should explore a new path to address the long-existed excessive energy consumption and pollution problem. At the same time, the concept of sustainable architecture is put forward as a solution to the issue. In the past few years, innovations and breakthroughs have taken place in the construction industry and relevant strategies have been adopted by many projects. However, in order that the future of architecture will be rooted in nature and benefit the human well-being, the concept of sustainable architecture should be popularized extensively instead of serving as pioneer projects. This present article aims to assess the current actuality of sustainable architecture, including its prospects and obstacles. Also, it will propose several strategies with respect to developing eco-friendly building materials, adopting energy-efficient building design, and promoting vertical green facades along with one or two real-life cases.

Keywords: Sustainable architecture; energy-efficient; design; prospect; strategies.

1. Introduction

Sustainable architecture is a concept becoming the mode in the past 20 years. It aims to minimize the negative environmental impact by improving energy efficiency, adopting eco-friendly building materials, etc. However, the reality is that we are not that close to living in an energy-efficient building. Conventional architecture is energy-intensive in both the construction process and operational use process. Take China as an example (Fig. 1), the overall energy consumption of architecture was 9.46 hundred million tons of standard coal equivalent (tce) in 2005, which took up about 36.19% of the final energy consumption that year [1]. Nevertheless, energy consumption had been on the rise in the 15-year period to 22.7 million tons. The proportion of it was strikingly 45.5% in the final energy consumption, which means it is possible that the energy consumed in architecture will take up half of the country's total energy use unless effective measures are taken. Carbon emission is another non-negligible problem that is the main cause of climate change and its relevant consequences. Greenhouse gas (GHG) emitted from building materials, construction, and other relevant processes takes up about 40% of the total GHG emission [2]. Over the next several decades, building construction will continue to grow at an unprecedented speed. It is estimated that 230 billion square meters will be constructed in the next 40 years which is equal to adding a Paris to the planet every single week. Then we will face the dilemma of energy scarcity and consequences due to carbon emission.

To achieve the sustainable development goals in this energy-intensive industry, it is essential to cut down the consumption, find ways to ensure energy efficiency, and even innovate to generate energy for internal use. There have been studies analyzing the future concerning the benefits and barriers of the concept or experimenting with eco-friendly building materials. However, this study tends to provide an overall review of the current development in the field of sustainable architecture with practical examples, which may offer readers a more comprehensive perspective.

Starting with the definition and the authoritative rating system, this study analyzes the promising advantages that green buildings may bring about and also the obstacles we are facing when striving

to popularize them. Strategies including selecting environmentally friendly building materials, adopting energy efficient design, and promoting vertical gardens are evaluated with practical case studies.

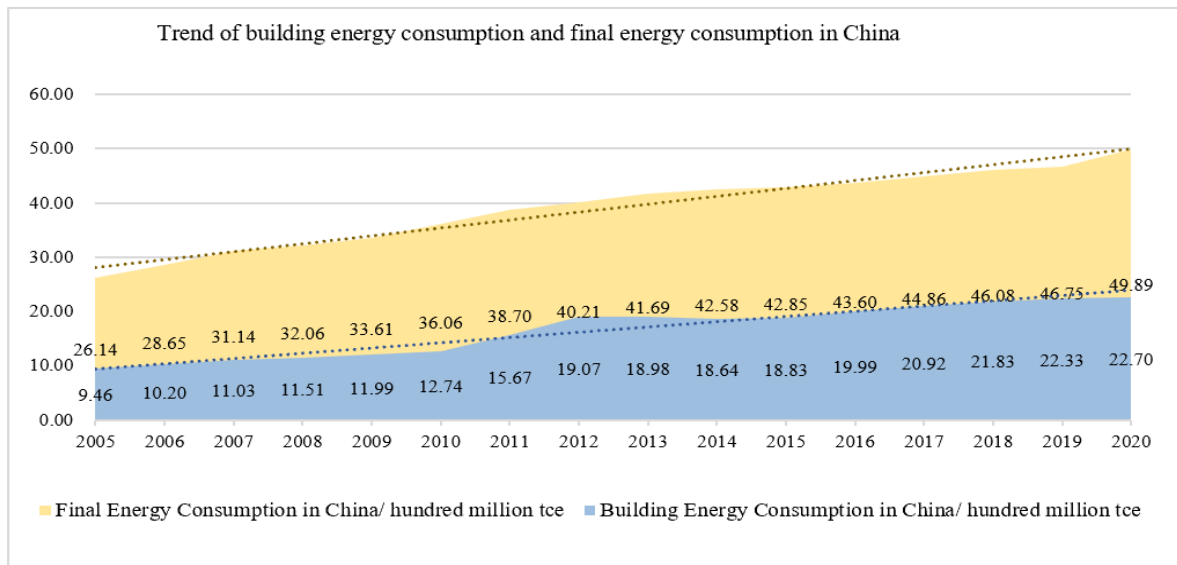


Fig 1. Trend of building energy consumption and final energy consumption in China.
<https://www.cabee.org/>

2. Sustainable Architecture

2.1. Definition of Sustainable Architecture and Current Rating Program

Sustainable architecture (green building) is the practice of construction in a way that is both environmentally friendly and resource-efficient throughout a building’s life cycle [3]. Conducting it needs collaboration among design, construction, operation, maintenance, and even demolition. Before the concept of sustainable architecture was proposed, the term “solar architecture” revealed the outline of reducing the construction of conventional resources by using renewable solar energy. The evolution of the term brings us to the current and broader concept of “sustainable architecture”.

There have already been some rating systems in architecture to determine whether a building is eco-friendly and to what extent the building consists of the principle of architecture. One of the most authoritative programs is the Leadership in Energy and Environmental Design (LEED), which is developed by the non-profit U.S. Green Building Council [4]. It includes a set of elaborate rating systems in massive fields of design, construction, operation, and maintenance of green buildings, residential buildings, neighborhoods, etc. To achieve a LEED certification, a building needs to fulfill several specific prerequisites. As long as the requests are met, the building is qualified to earn LEED credit through the point system which contains carbon emission, energy efficiency, water usage and management, health, etc. The highest level of LEED certification is Platinum Certification, requiring more than 80 credits [5]. Receiving the LEED certification demonstrates that the building’s commitment and long-term determination in sustainability are at the highest level in the world. What’s more, given the rule that a project which has already had a LEED certification is welcome to strive for a higher standard of certification, the rating system effectively enhances the investment, continuous innovation, and maintenance in the accredited building.

2.2. Prospect of Developing Sustainable Architecture

The significant benefits of adopting sustainable building lie in cost savings, reduced carbon footprint, increased air quality, etc. [6]. First of all, developing sustainable architecture means pursuing energy efficiency and the net zero goal. Green buildings require the designers to turn to

clean energy instead of non-renewable energy such as coal, which will significantly reduce carbon emissions. To actually achieve this, more solar panels will be installed and windows will allow in more natural light to reduce artificial light. Also, incorporating air sealing and insulation is adopted in green construction so that the loss of heating and cooling is reduced. As mentioned above, conventional architecture has taken up a large part of final energy use and total carbon emission in many countries. In accordance with the EPA, a LEED-certified building averagely reduces 30%-50% of energy use than conventional construction [7]. In addition, sustainable architecture reduces the cost of maintenance and operation. Eco-friendly building materials usually have a longer lifespan and are more durable. Green buildings are designed to be equally friendly featuring solar panels, insulation, and lightning, so they effectively reduce energy consumption and expense. Another benefit of sustainable architecture worth mentioning is that it ensures good indoor air quality, which has a positive effect on human bodies. Fewer toxins and allergens are released by the green building materials, which positively affect the overall well-being of the family. More natural light is allowed in the green building and a ventilation system is adopted, diluting the concentrations of carbon dioxide, nitrogen dioxide, and other harmful chemicals in the building. It, in turn, reduces the stress on the human body.

2.3. Barriers to Conducting Sustainable Architecture Concept

The idea of sustainable architecture may be attractive and promising, and significantly reduce GHG emission and probably contribute to carbon-neutral ambition, however, there are several barriers that can't be ignored. Lacking awareness among the public is the major obstacle in promoting sustainable buildings in most developing countries, according to a Malaysia report [8]. Many developers and clients are ignorant of the literal benefit of implementing green buildings and sustainability concepts. Also, the absence of financial support from the government and a lack of skilled labor when it comes to specific techniques in the construction process make the estate agency unwilling to invest in building sustainable buildings while taking many risks. Many designers and engineers haven't been comprehensively equipped with the capability to outline and construct the whole sustainable architecture, so some current designs aren't practically sustainable in some stages [9]. In addition, although there are encouraging eco-friendly construction materials put forward, many of them aren't put into manufacture which means they are not accessible to most of the developers. They are also expensive currently, discouraging developers who have limited budgets. Granted that the sustainable design hit the ground, it takes a longer time to recover the economic payback which is also unpredictable for most investors. This, in turn, prevents sustainable architecture from implementation in many regions.

3. Measures to Improve Architecture Sustainability

3.1. Environmentally Friendly Building Materials

The construction process plays a vital role in the life cycle of a building. A sustainable design lays the foundation for the building's character of energy-efficient and eco-friendly. A promising solution is a phase-change material (PCM). It is a substance that releases or absorbs a considerable amount of energy at the phase transition to achieve the purpose of heating or cooling. Given this characteristic, PCMs have an outstanding performance in energy storage (Fig. 2) and can save about 5 to 14 times more energy in one unit volume than water and rock [10]. There are mainly 4 types of PCMs adopted in building construction, which are solid-solid, solid-liquid, gas-liquid and gas-solid. The solid-liquid PCM has 3 sub-categories: organic, inorganic and eutectic. PCMs can be adopted in various parts of the construction process. For instance, it can be installed in the external windows in some old buildings, which is the easiest way in this case. While in the construction process, it can be incorporated into the ceilings, roofs, walls, etc. It is suggested that PCM methods demonstrate positive results in various regions, especially in a moderate climate. Using PCMs in construction reduces the building's carbon emissions. However, the production process of conventional PCM itself

emits many harmful substances. For example, manganese nitrate hexahydrate has the most tremendous global warming potential (GWP) as it releases greenhouse gases like carbon monoxide. So, it is crucial to find substitutes that are more environmentally friendly. Currently, bio-based materials like coconut oil produced from bio-fertilizers and plant-based materials are favorable alternatives to conventional PCMs [10].

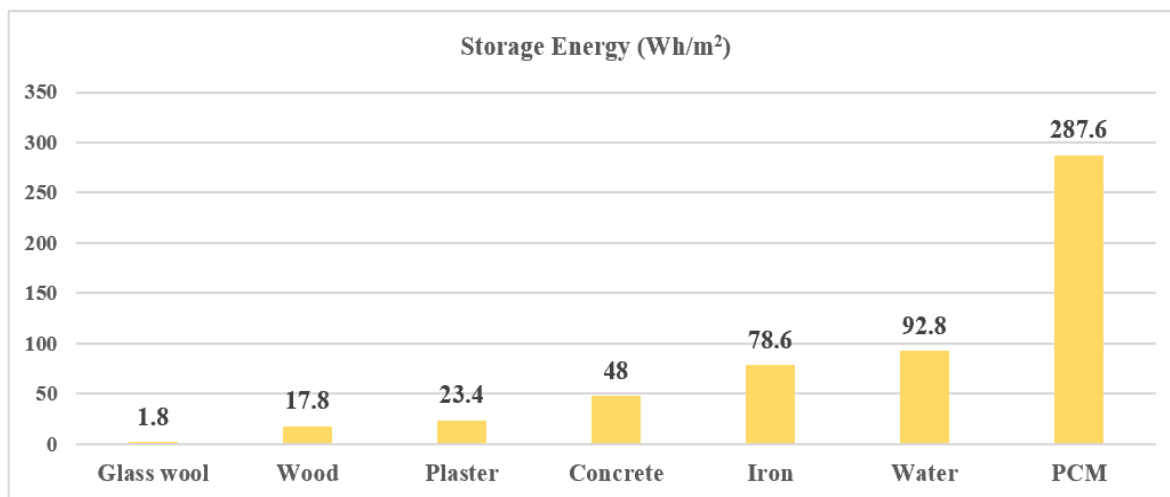


Fig 2. Storage energy of several building materials. <https://doi.org/10.1016/j.ecmx.2022.100237>.

Another encouraging sustainable building material is 3D concrete printing (3DCP). It has been adopted in construction as an alternative to the conventional method. Cement alone takes up 8% of the carbon emissions, while it is still needed even in buildings using green processes. Given the situation, there is great potential in changing the way cement is prepared and its sustainability, especially for complex construction. The printed polymer composite developed by Mighty Building weighs 30% less than cement and has better tensile resistance and flexibility [11]. Although 3DCP isn't manufactured due to the technical limitations, and the cost is higher than traditional concrete, if we can increase the aggregate sizes like the concrete construction, then 3DCP will be more sustainable and cost-saving. Another advantage of 3DCP is that it uses raw materials when producing. A 3DCP company stated that in comparison with traditional concrete production, 3DCP only needs 45% of the infill [11]. It is extremely welcomed in the resource-scarce reality if 3DCP can further combine with topology to enhance its volume of material while considering the loading conditions.

3.2. Energy-Efficient Building Design

As mentioned above, large energy consumption is a main problem of conventional architecture. So, energy-efficient design is crucial including using renewable resources and passive strategies to improve lighting, and ventilation relying on nature. Building envelope such as a green roof or efficient thermal insulation material reduces energy loss when using a cooling or heating system. This will help reduce the cost of energy in the operation process. Installing solar panels and wind turbines on the top of skyscrapers or reusing waste to produce biogas can provide a portion of the internal energy use. The localized electricity generation eliminates the possible loss in the transmission and distribution process, which also contributes to energy efficiency. These measures are all helpful to decrease the carbon footprint and contribute to the net zero ambition.

Located in the central business district (CBD) of Shanghai, Shanghai Tower is the tallest and largest LEED Platinum-certified building in the world since 2015. It fulfills the concept of sustainable architecture in various ways. There is a rainwater capture structure that provides part of internal water use such as toilet flushing and landscape irrigation, and it also treats a portion of the wastewater [12]. The water can be stored temporarily in the interim water storage tank within the tower. It allows the water pressure to be maintained by gravity. These strategies lead to 38% less water consumption. The building is equipped with 2 chiller plants [12]. One is on the B2 floor, and the other is on the 82nd and 83rd floors. Having 2 chiller plants reduces the energy consumption of pumping the water

throughout the facility and effectively avoids a loss. The transparent glass façade twists 120 degrees (Fig. 3) as it rises to reduce wind loads. It effectively saved construction materials, which is, in turn, cost-saving. What's more, there are 270 vertical-axis wind turbines installed near the top of the tower to generate electricity taking advantage of the fierce wind there. They are able to produce up to 350,000 kWh of supplementary electricity per year [13-15]. Another highlight of the Shanghai Tower design is the 2 separate curtain walls which have multiple functions (Fig. 4). As the tallest building in China, lighting is one of the largest energy drains. The glass curtain walls allow natural light which significantly cuts down the energy consumption of artificial light. The reinforced glass with a high tolerance for temperature change reduces heating and cooling loads and the atrium conserves energy by modulating temperature. The void space serves as an insulation and keeps heat in the building in winter while limiting heat gain in summer.

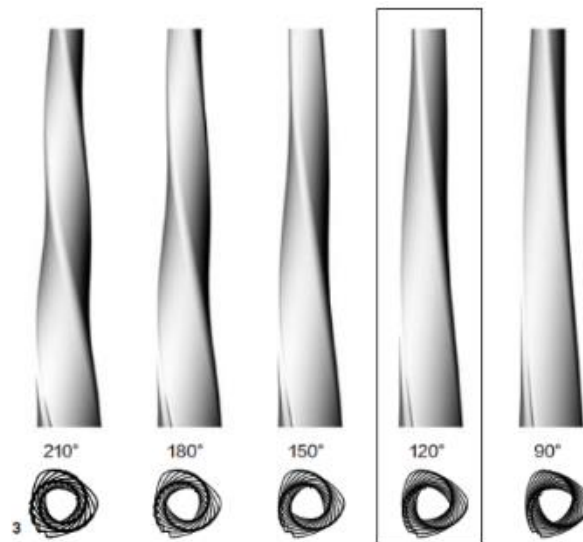
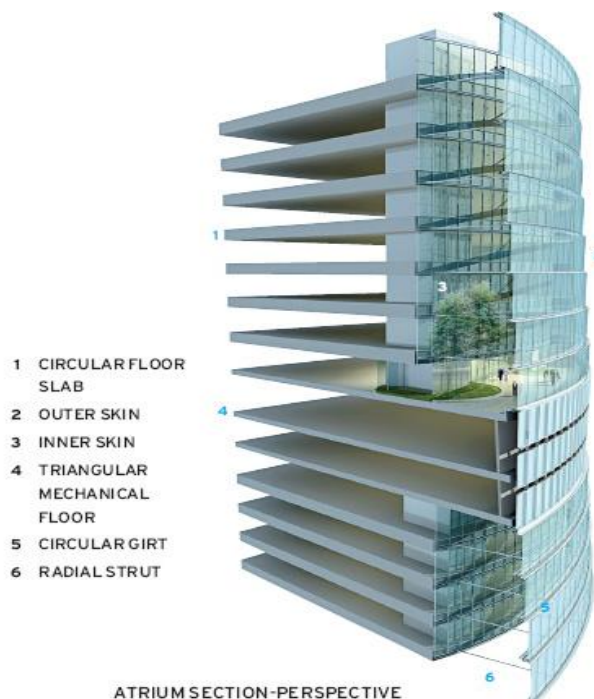


Fig 3. Rotation model of Shanghai Towerjenny Filippetti I designboom.
<https://www.designboom.com/architecture/skyscraper-news-shanghai-tower-vertical-skyscraper-races-the-future-is-lego/>



ATRIUM SECTION-PERSPECTIVE

Fig 4. Double-layer curtain walls.
<https://www.architecturalrecord.com/articles/10084-shanghai>. (Tower.)

3.3. Vertical Green Façade

Vertical green façade is vital in filtering air compounds, regulating the temperature, reducing the heat island effect, etc., especially in tropical regions. The green façade usually adopts climbing plants or uses specific modules installed in the façade to grow plants [16]. However, it is worthwhile to note that the climbing plants usually have strong roots and will gradually damage the façade structure and are hard to remove later. Allowing more cross-ventilation, the green façade may also serve to increase the productivity and well-being of the dwellers.

One Central Park (OCP) in Sydney stands out with its living façade. Initially, the building tended to serve as a small park in the community. But the construction turns out to be another pioneer in sustainable architecture. The plants in vertical walls and horizontal boxes are irrigated by grey water and grow in a nutrient solution instead of soil, applying less pressure to the load-bearing design. The shading from the leaves cancels out 20% of the thermal impact which helps regulate the temperature [17]. Unlike the common glass curtain walls adopted by many public buildings, the green façade reflects less heat and functions to absorb carbon dioxide while emitting oxygen.

Another practical example is Bosco Verticale (Vertical Forest) in Milano, Italy. Consisting of 2 residential buildings, the ambitious project has 730 trees including shrubs (Fig. 5), which equals a hectare of forest. According to the designer, the Vertical Forest emits oxygen, filters small particles produced by the vehicle, adds humidity to the atmosphere, and regulates the temperature [18]. The foliage also functions as a protection screen against solar radiation, a windbreak, and a muffler plate against noise pollution [19]. The serried forest provides a habitat for birds as well, contributing to the balance of humans and nature in the metropolis.

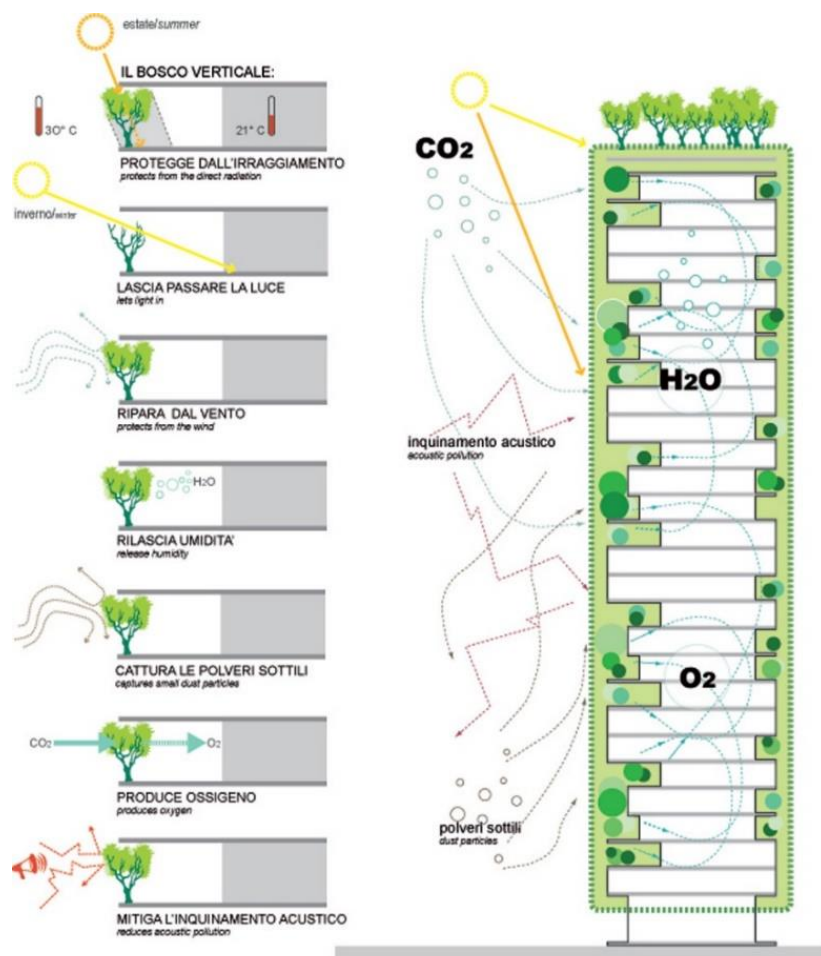


Fig 5. Bosco Verticale life cycle.

https://www.researchgate.net/publication/322739201_China's_Nanjing_VS_India's_Delhi_-_A_perspective_for_vertical_forest.

3.4. Case of Pixel Building in Melbourne, Australia

The Pixel Building completed in 2010 is the first carbon-neutral office in Australia generating all its internal power and water usage. In 2012, it received LEED Platinum certification with a score of 105 points out of 110. The concrete used in the building is a patent-protected product developed by Grocon. It almost halves the embodied carbon when compared with conventional concrete. The noticeable colorful façade is made of recycled panels which are designed to provide maximum daylight and shade and minimize the energy consumption in cooling and heating (Fig. 6). Another system for cooling and reducing energy consumption is its air circulation system cooperating with the water-cooled ceiling. Fresh air is absorbed into the building and circulated throughout the floor spaces. There is a heat exchanger at the entrance of the air pipe to capture energy from the exhaust air to pre-cool or pre-heat the fresh air [20]. The gas-fired ammonia absorption heat pump at the next stage works to cool the air further and pump it down to each level. After circulating in the office, the warmer air rises to the upper space and is purged outside via a specific pipe. The water circulated in the ceiling via a high-density polyethylene pipe (HDPE pipe) allows radiant cooling [20]. The openable windows in the office allow convection and cooling of the ceiling slab. In terms of the low demand for energy use due to the design of the pixel building, solar panels and vertical-axis wind turbines (Fig. 7) are installed on the rooftop to cancel out the rest of the carbon emissions. They also serve to export renewable energy and gain economic benefits if excess electricity is generated. Additionally, a small amount of biogas is produced from an anaerobic digester in the toilet black water system. Fig. 8 shows the gas and water circulation system.

The Pixel Building also contains a water treatment plant (Fig. 9) to achieve water neutrality. Extensive green rooftops and planters on each level served to filter the rainwater and transfer water to the water storage tank underground [20]. Grey irrigation water will be treated there to meet the standard of basins, showers, and toilets and pumped to every stage. Black water from the toilet is discharged to the sewer while the grey water from the basins goes to irrigate the planters. The waste in the black water will be concentrated and sent to the anaerobic digester to produce biogas which served to heat water in the heating system. The water treatment system means that no grey water will be discharged from the Pixel Building unless the weather is extremely wet.



Fig 6. Recycled panels.

<https://cdn.archilovers.com/projects/4b28f524-bfac-47eb-93db-cc44f16bd2e4.pdf>



Fig 7. Vertical-axis wind turbines and solar panels.

<https://cdn.archilovers.com/projects/4b28f524-bfac-47eb-93db-cc44f16bd2e4.pdf>.

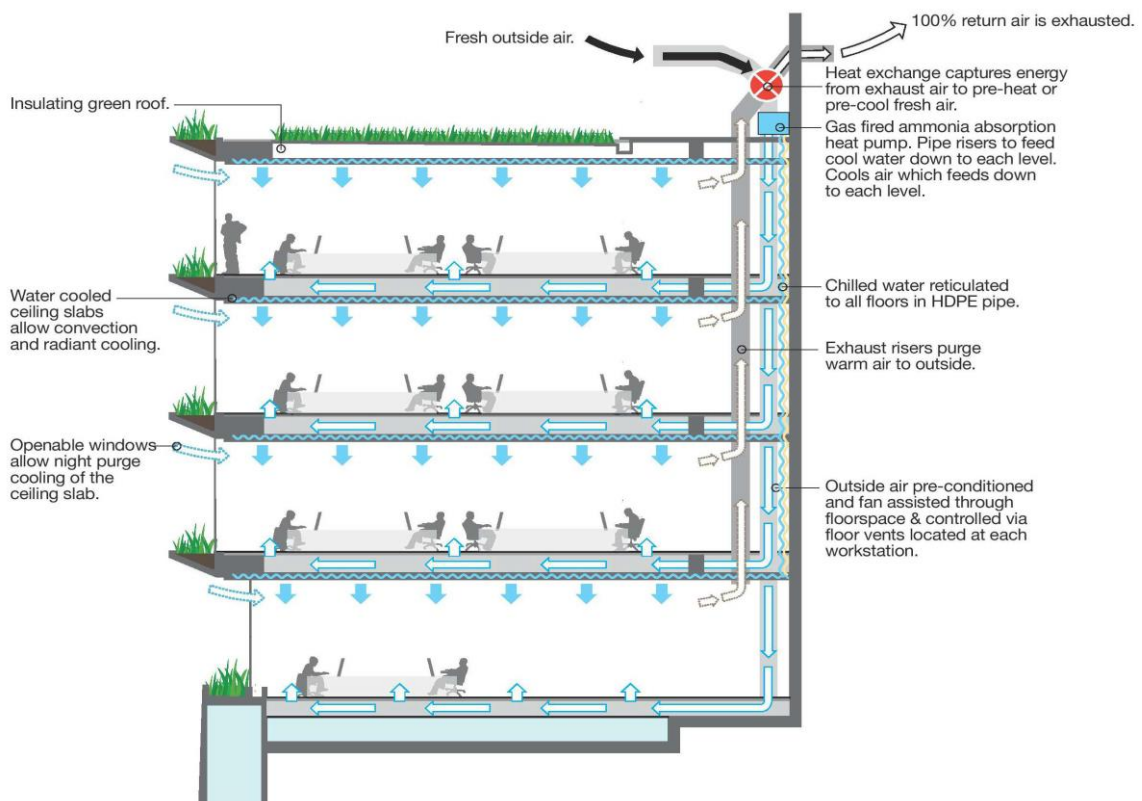


Fig 8. Gas and water circulation system.

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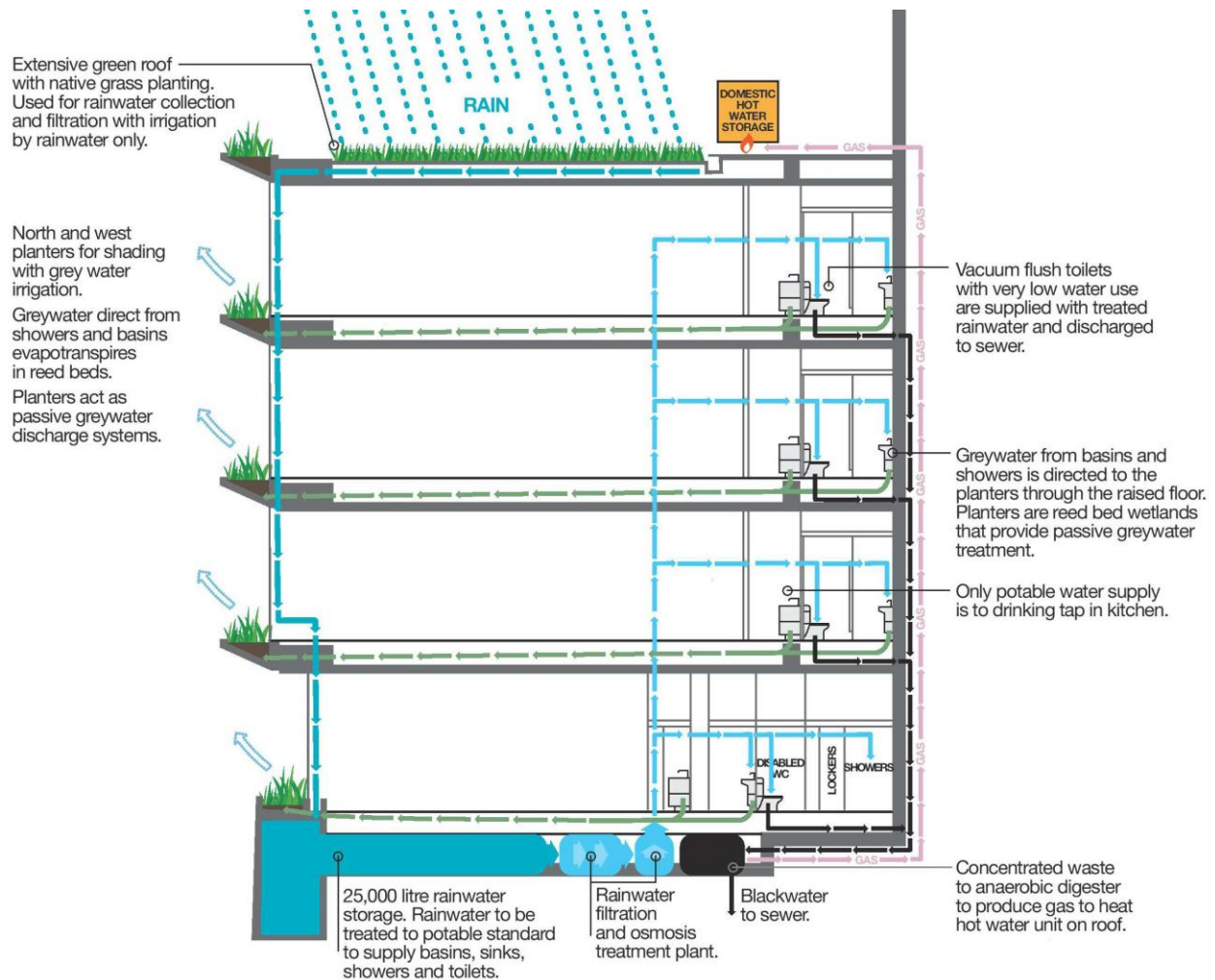


Fig 9. Water and waste treatment system.

<https://cdn.archilovers.com/projects/4b28f524-bfac-47eb-93db-cc44f16bd2e4.pdf>

4. Conclusion

This study explains the concept of sustainable architecture, analyzes the current actuality of it concerning both prospects and obstacles and provides a potential implementation strategy with practical cases. The benefits of green buildings lie in the characteristics of cost and energy-saving, toxic-free, and recycling, while the concept faces misunderstanding and ignorance in many developing countries which can be overcome by introducing policies to encourage relevant investment, raising developers' awareness on environmental issues and adding the concept to the standardized training to engineers and architects. There have been authoritative rating systems such as LEED which can also serve to promote green designs and long-term maintenance. Energy-efficient materials like PCM and 3DCP prove to be encouraging if manufactured and sold at a moderate price. Some pioneer sustainable architecture project has hit the ground with the potential to reach nearly net zero. In a time when human beings are facing environmental issues like global warming and resource shortage, there is no denying that sustainable architecture will continue to be the main research direction and trend in the construction industry with a promising future. Constructing wholesale residential buildings, remodeling conventional buildings with sustainable concepts, and exploring net-zero buildings may be the potential research topics in the future.

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