Healthy Building in China

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Healthy buildings are a deep-level development of green buildings, which can effectively help relieve stress and improve occupants' physical and mental health. In addition, they are is likely to play an important role in preventing the spread of respiratory infectious diseases. Therefore, healthy buildings have attracted worldwide attention. The development of healthy buildings in China is quite different from that of other countries and has its own characteristics with many factors, such as project implementation, environmental pollution, and social issues affecting healthy buildings development in China.

Keywords: healthy building ; China ; SARS-CoV-2 ; indoor air quality

1. Introduction

The first oil crisis in the 1970s brought a strong sense of energy crisis to the developed countries, which drove energy conservation measures. Since then, the building sector, which consumes a large proportion of total global energy consumption, has attracted widespread attention, and building energy performance has been improved [1]. However, due to excessive pursuit of building energy efficiency while ignoring other issues, the drawbacks of energy-efficient buildings began to appear after nearly 20 years of use. Employees in the office buildings became ill in those buildings due to poor ventilation [2], which greatly affected the occupants' living quality and productivity. The frequent occurrence of this phenomenon has triggered the research on Sick Building Syndrome (SBS). Poor indoor air quality was found to be the main cause of SBS. Building ventilation rate, thermostat settings, and pollutant emissions have important impacts on indoor air quality, all of which are closely related to heating, ventilation, and air-conditioning (HVAC) system control [3]. Poor design, installation, management and maintenance of the HVAC system lead to poor indoor air quality [4]. Proper design and installation of the HVAC system greatly contribute to the realization of "healthy buildings" [5]. Therefore, the miscoordination between the building design, operation, and construction process needs to be addressed to reduce SBS [6]. China has its unique feature in the building construction industry and the results from other countries could not be directly borrowed and applied to the healthy buildings in China [7]. Since the beginning of research on SBS in the 1990s, the concept of healthy buildings has gradually been accepted by the general public. Building materials received wide attention at the beginning and have been considered as the main indoor pollution source [8].

The rapid urbanization and economic development over the past 20 years in China have caused a series of environmental problems such as indoor and outdoor air pollution, water pollution, energy shortages, and human-related problems. These problems are superimposed and magnified at the specific building level. Specifically, most people have a high degree of understanding on indoor $PM_{2.5}$ control measures and ambient air quality, but a low level of self-awareness, so that wrong behaviors of window opening often lead to failures in indoor $PM_{2.5}$ pollution control [9]. Ambient air pollution in China has greatly affected the energy-saving and emission-reduction potential of natural ventilation [10], and natural ventilation is one of the key measures of ensuring human health by supplying fresh air [6]. The small number of buildings certified by the healthy building standards indicates that the implementation process of human-centered measures in the construction industry is still in its infancy [11]. In addition, the concentration levels of indoor $PM_{2.5}$, formaldehyde and many other volatile organic compounds (VOCs) are much higher than those of developed countries such as the United States, causing much greater health hazards [12]. Those problems will prevent the implementation of the "Healthy China Strategy". As the impact of the built environment on human physical and mental health is significant, it calls for more attention to healthy buildings in China [13], which may be an effective way to alleviate some of the above-mentioned problems [14].

The SARS epidemic in 2003 caused people to pay attention to the problem of "building-related diseases", and propose that building design is interrelated with infectious diseases [6]. SARS has exposed the drawbacks of traditional architectural design, and reminded us to pay attention to health requirements factors in building design, and more importantly, to improve the "immunity" of residential zones against infectious diseases through urban planning, building design, construction, and community service systems [15]. Since the beginning of 2020, after SARS, the outbreak of the COVID-19 epidemic has given us a further understanding on buildings and health. A large number of indoor cases reminded us to create a healthier, more comfortable, and livable indoor environment [16]. At the same time, the needs of the elderly when facing the epidemic deserved great attention in a dense population. Suitable community scale, unified unit planning, urban governance, and reasonable functional space planning are the important areas that should be concentrated on [17]. During the post-epidemic period, the construction of healthy buildings has now received wide attention. People's demand for housing has changed from owning a simple house into the pursuit of a healthy and comfortable living environment and satisfying humanistic needs [18].

2. Development of Healthy Buildings in China

2.1. Milestones of Healthy Buildings Development in China

It has been more than fifteen years since the concept of “healthy building” was introduced in China. However, in the first ten years, there were almost no domestic studies on healthy building technology. In the 1990s, energy-saving was promoted globally and a few scholars first put forward the concept of low-energy-consumption healthy buildings in China. For example, Hong et al. [19] pointed out that low-energy healthy buildings are the key to sustainable development and introduced the possible road map for low-energy healthy buildings. These studies have laid the foundation for the development of healthy buildings in China. In recent years, the development of healthy buildings has become more rapid and mature with the support of the Chinese government. In particular, the release of China’s Healthy Building Standards in January 2017 encouraged many scholars to carry out studies on healthy buildings, and a large number of healthy building projects have also emerged. **Figure 1** summarizes the variation in the number of papers published on healthy buildings from the three most popular academic journal databases in China, i.e., CNKI, CQVIP, and Wanfang. **Table 1** lists the milestones of healthy building development in China.

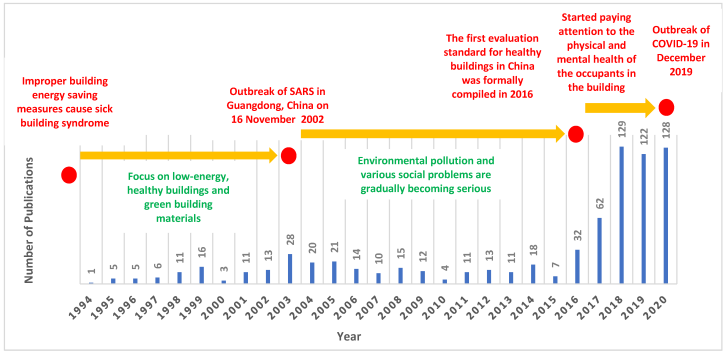

Figure 1. Variation trend on the number of papers published related to healthy buildings in China.

Table 1. Milestones of healthy building development in China.

Time	Event	Refs.
27 March 2015	The WELL building standard was officially introduced to China by the China Green Building Certification Association (GBCI) and the International WELL Building Research Institute (IWBI).	[20]
3 December 2015	The Sino-Ocean Group introduced the WELL certification into the Chinese market and assisted China and the United States in jointly holding the launching ceremony of China’s first WELL healthy residential area certification. The Guangzhou Sino-Ocean Tianjiao project obtained China’s first WELL residential gold registration and WELL residential gold delivery certification. The world’s first WELL multifamily residential (MFR) gold certification project.	[21]
11 August 2016	The China Quality Certification Center, the China National Engineering Research Center for Human Settlements (CNERCHS), and the China Industry Technology Innovation Strategic Alliance for Housing jointly held a work seminar on the plan for HiB (Health in Building) healthy building certification launch and pilot project kick-off in Beijing.	[22]
25 October 2016	The Central Committee of the Communist Party of China and the State Council issued the “Outline of the “Healthy China 2030” Plan”, which clearly put forward a national strategy to promote the construction of a healthy China.	[23]
6 January 2017	The ASC issued and implemented the “Healthy Building Evaluation Standards” (T/ASC 02-2016).	[24]
23 March 2017	Construction21 (China) was formally established, and the Chinese Academy of Building Research is the undertaking organization of Construction21 International Organization in China.	[25]
18 April 2017	The inaugural meeting of the healthy building industry technology innovation strategic alliance and the first working meeting of the first council was held at the China Academy of Building Research. The alliance is responsible for organizing and carrying out the work of Construction21 (China).	[26]
16 November 2017	CNERCHS, the ASC, the China Real Estate Association, and the China Industry Technology Innovation Strategic Alliance for Housing jointly held the 9th Forum of Theory and Practice on Healthy Housing, 2017 in Hangzhou. The inaugural meeting of the Healthy Human Settlements Academic Committee of the ASC was held at the same time.	[27]
22 March 2019	“2019 (The First) Healthy Building Conference” was held in Beijing.	[28]
23 July 2019	The Ninth International Conference on Sustainable Development of Building and Environment (SuDBE2019), co-sponsored by Chongqing University; the University of Reading, UK; and the University of Cambridge, UK, was officially held at the University of Reading, UK.	[29]
22 October 2019	Central South University and the International Society for Indoor Air Quality and Climate (ISIAQ) hosted the “Healthy Buildings 2019 Asia” in Changsha. It was the first international conference on healthy building held in developing countries.	[30]

Time	Event	Refs.
21 May 2020	The “Healthy Building Alliance 2020” annual report was officially released.	[31]
8 September 2020	China Academy of Building Research Co., Ltd. and other institutions co-sponsored the online “2020 (The Second) Healthy Building Conference,” with the theme of “From healthy buildings to healthy communities, and building healthy human settlements together.”	[32]
29 November 2020	The Healthy Building Industry Technology Innovation Strategic Alliance and the China Building Research Institute Co., Ltd. hosted the “2020 Healthy Building Industry Innovation and Development Summit Forum” in Beijing, and the “Healthy Community Evaluation Standards” T/CECS 650-2020 T/CSUS 01-2020 promotion meeting.	[33]

2.2. Healthy Building Project Development

The evaluation of healthy building labels in China has been implemented since 2017. It is organized and promoted by the China Urban Science Research Association. The evaluation of healthy buildings is divided into “design evaluation” and “operation evaluation”. “Design evaluation” focuses on health concept application in architectural design, while “operational evaluation” focuses on the health performance of the building in operation. In the WELL standard, the project obtains corresponding credits based on the health effects produced by the design, operation, and management measures, and finally receives certification based on the total credits. The certification levels are ranked from low to high into bronze, silver, gold, and platinum [34]. **Table 2** lists some typical healthy building demonstration projects in China. As the evaluation scope and weighting factors for each concept are different, it is hard to determine which one has stricter requirements. **Figure 2** and **Figure 3** provide two examples of the certified buildings, the China Petroleum Tower and Hangzhou Landsea Huafu Residential District. **Table 2** gives a detailed introduction to the technologies and services applied in some demonstration projects of healthy buildings in China from the six evaluation concepts of healthy buildings.

Figure 2. China Petroleum Tower (from Baidu Map).

Figure 3. Hangzhou Landsea Huafu Residential District (from Baidu Map).

Table 2. Healthy Building Demonstration Projects in China.

Project	Location	Building Type	Total Construction Area (m^2)	Label Grade	Green Energy-Saving Measures			Measures of Human Ser	
					Air	Water	Comfort	Fitness	Humanitie
China Petroleum Tower	Beijing	Office	2.008×10^5	Three stars Operation	Multifunctional air purification device and air ionization evolution technology, five-parameter air quality online monitoring, central dust collection system, and independent exhaust system in special areas.	Direct drinking water purification device, domestic hot water from the urban heating pipe network, reclaimed water recovery system.	Intelligent control VAV system; intelligent louvers and lighting; double-layer internal breathing glass curtain wall.	Various indoor fitness venues and a shared ecological space of nearly 5000 m^2.	PetroCl Exhibitio a books and a 6 person le hall
Hangzhou Landsea Huafu Residential District	Hangzhou	Residential	1.365×10^5	Three stars Design	High-efficiency haze removal fresh air system, zero-formaldehyde control of decoration materials, indoor pollutant concentration, particulate matter pre-assessment, and air quality monitoring and report system, etc.	Water quality control, detailed water supply and drainage systems design, and water quality monitoring.	Centralized fresh air system, household humidifier, indoor lighting simulation, three-layer glazing with two-cavity high-performance energy-saving windows and sound-absorbing and shock-absorbing building envelope materials.	An outdoor fitness venue of 532 m^2.	Childr activity a elderly ac venue communi venues,
Building 4, Foshan Contemporary World Mansion MOMA	Foshan	Office	8.7×10^3	Three stars Design	Constant temperature and humidity control room air-conditioning system, displacement fresh air supply.	Ultraviolet sterilizer for living water tank, floor lowering same-layer drainage system.	Sound insulation screens, green belts, and three-layer vacuum glazing for external windows.	Indoor and outdoor venues, open all day.	Exclus space owners ages to the nee communi commutir exerci
Buildings 27–28, 30–36, Jianfa Yangxi	Shanghai	Residential	9.75×10^4	Three stars Design	Room fresh air system, decoration material pollutant control, and indoor pollutant concentration pre-assessment, etc.	Pre-filtration, central water purification, end water purification device, and water quality inspection management system.	Sound insulation and noise reduction measures, daylighting, and natural ventilation.	Fitness venues and fitness equipment design.	Communi and act venues residen differen group reasona artwor arranger
Sino-Ocean Group Headquarters	Beijing	Office	6.7×10^5	WELL Platinum	Comprehensive management platform for air quality.	High-quality drinking water.	Sound-absorbing materials in the office area.	Indoor fitness circuit.	Artwo decorat outdoo internal vi windows marine-th sculptu

Project	Location	Building Type	Total Construction Area (m^2)	Label Grade	Green Energy-Saving Measures			Measures of Human Ser	
					Air	Water	Comfort	Fitness	Humanitie
Buildings 8–10, Beijing MCC Dexian Mansion	Beijing	Residential	4.1×10^4	Two stars Design	Haze-removal fresh air system, indoor decoration materials meeting stricter health standards than national standards.	Centralized direct drinking water system, high-quality pipes and independent circulating network.	Design that fully considers the climatic region and living style of the northern area, three-layers double hollow, and LOW-E glazing for external window.	Community service center, cultural and sports activity station, and fitness sports venue.	Indoor outdo childre activit venue
Junyi Oriental Houze Garden	Nanjing	Residential	5.54×10^4	Two stars Design	Full heat-recovery haze-removal fresh air system.	Same-floor drainage, kitchen and bathroom diversion, whole house water purification system.	High-performance sound attenuation window	Outdoor fitness venue.	All-aged a venues gardens, green s rate of 36
Lihu Jinmao Mansion	Wuxi	Residential	3.04×10^4	Two stars Design	Centralized heat recovery fresh air system.	Whole house water purification system and terminal direct drinking water system, same floor drainage	Temperature and humidity control system.	Home owner fitness sports venue.	Outdo communi and ev venue

2.3. Benefits of Healthy Buildings

The benefits of healthy buildings determine the development of its technology and industry. An in-depth analysis of the benefits of healthy buildings can not only obtain the economic parameters of healthy buildings and find the economical and healthy technical solutions, but also make the general public fully aware of the feasibility of healthy buildings and promote the rapid development and progress of this industry.

The fundamental concept of a healthy building is to help the building occupants achieve their physical and mental health, and extend their lifespan. The Global Burden of Disease 2010 (GBD 2010) study shows that in 2010 the deaths due to outdoor air pollution ($PM_{2.5}$) in the world were as high as 3.22 million, and the disability-adjusted life years (DALY) caused by $PM_{2.5}$ pollution accounted for 3.1% of the total DALY [47]. It was reported that in 2016, the three major risk factors of metabolism, environment, and behavior led to a total of 155.629 million DALY losses in China, accounting for 44.8% of the total DALY, of which air pollution factors accounted for 9.3% [48]. Studies have revealed that the disease spectrum of Chinese residents has undergone major changes, and chronic non-infectious diseases have replaced infectious diseases as the main cause of death and disease burden [49]. Healthy buildings can help to minimize indoor air pollution and achieve healthy lifestyles, which is a fundamental measure for treating and managing chronic conditions, and reducing the prevalence of chronic diseases can effectively lower residents' medical expenditures.

Although the healthy building industry has developed in China in recent years, the number of studies on its economic benefits is still limited. Li [50] conducted an economic analysis on a commercial real estate in Guangdong Province and found that the investment cost increased by 2.15% or 298.36 ¥/m^2. The selling price increased by 1330 ¥/m^2 with gross profit increased by 2.44% and net profit increased by 1.17%. Therefore, there is a cost–benefit potential in the development of healthy buildings in China. According to the "China Healthy Building Development Research Report 2020", compared with ordinary buildings, the incremental cost of healthy buildings is 120–500 ¥/m^2 [51]. The report also stated that with the maturity of technologies and marketization, the incremental cost of healthy buildings could also be further reduced. In addition, the indoor environment directly affects the work efficiency of employees, and the improvement of air quality can increase the productivity by 8–11%.

The above indicates that healthy buildings cannot only provide health benefits, but also economic benefits. While the health benefits are obvious, few studies have analyzed the economic benefits. It is recommended to include more healthy building case studies in future research to clearly exhibit the economic benefits.

3. Conclusions

Healthy buildings pursue the physical and mental health of the human body under the premise of energy conservation and environmental protection and the unique concept of “human-centered design”, representing a manifestation of the progress of human civilization. It is foreseeable that healthy buildings will become the new direction for the development of the construction industry in the future. Presently, there is a series of problems such as insufficient fundamental research, unqualified building projects, lack of education on the awareness of healthy buildings, and flawed standard systems, which have severely restricted the development of healthy buildings. In order to further expand the impact of healthy buildings and bring more benefits to residents in the future, the following suggestions are made:

(1) Strengthen the cross-integration of multiple disciplines. In response to the multidisciplinary needs of healthy buildings, the universities can set up interdisciplinary courses and research centers that integrate the disciplines of building, material, information, and health, with the support of available funds from the government to promote infrastructure construction, and provide long-term and stable support for fundamental research on healthy buildings.
(2) More results can be carried out on the benefits of healthy buildings, especially on improving the health of the residents and cost-effectiveness of the project, to improve the awareness of the public.
(3) The government can develop financial incentive policies to promote healthy building implementation, e.g., covering 10% of the project cost, based on the measured results at the operation phase and develop a five-year development plan to promote healthy building construction.
(4) The enterprises can reserve and seek funds from the government incentive program to strengthen the education and training of healthy building knowledge and technologies to improve their employees’ ability to work on healthy building projects in their yearly plans.

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