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A Comparative Study on Technical Standards for the Design of Emergency Medical Facilities in China in the Context of COVID-19

Hui Ji [1], Lewen Huang [1], Haoming Li [1], Jiangtao Zhang [2], Qinlong Jing [3] and Ji-Yu Deng [1,*]

[1] School of Architecture and Urban Planning, Guangdong University of Technology, Guangzhou 510080, China
[2] Medical Care and Health Research Center, Shenzhen General Institute of Architectural Design and Research Co., Ltd., Shenzhen 518000, China
[3] Guangzhou Center for Disease Control and Prevention, Guangzhou 510440, China
* Correspondence: jiyudeng@gmail.com

Abstract: The technical standards for the design and construction of emergency medical facilities play an important role in guiding the conversion of Fangcang shelter hospitals and the construction of emergency infectious disease hospitals and temporary facilities for medical quarantine and observation. However, due to the imperfections and superficialness of the current version of the existing technical standards, further improvement and optimization on the maturity and systematism are necessary. This paper presents an in-depth analysis and comparison on the detailed regulations and terms between the existing 11 sets of technical standards issued by the National Health Commission (NHC) and the provincial competent authorities of Hubei, Zhejiang, Jiangsu, Hebei, Shandong and Beijing. The similarities, disparities and deficiencies of these technical standards are summarized. Then, the primary contents, including the site selection and architectural design, heating, ventilation and air conditioning (HVAC), structural design, electricity intelligence, water supply and drainage, operation and maintenance, environmental health and safety, and fire protection, are analyzed in-depth from the view of infectious disease control and health safety. Furthermore, some critical principles related to the detailed terms of the architectural design, HVAC, electricity and water supply are concluded. Finally, some essential suggestions are proposed for the improvement and revision of these technical standards for better applications.

Keywords: COVID-19; Fangcang shelter hospitals; emergency medical facilities; technical standards; design guidelines

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1. Introduction

"Preparedness ensures success and unpreparedness spells failure." (*The Book of Rites-The Doctrine of the Mean* (500 BC), one of the classic works of Confucianism and a part of the Confucian canonical scriptures, which reflects traditional Chinese cultural characteristics.)

Since the rapid spread of COVID-19 at the end of 2019, many cities in China have converted existing buildings, such as stadiums, convention and exhibition centers, large warehouses, etc., into temporary medical facilities for hospitalizing and treating patients with mild symptoms of COVID-19. Hence, these temporary medical facilities, namely "Fangcang shelter hospitals", came into the public eye, as an important part in the construction of urban health and epidemic prevention hardware facilities. At the beginning of 2020, the emergency use of Fangcang shelter hospitals in Wuhan set a precedent in the world (Figure 1). However, in terms of the actual operation effect of medical facilities temporarily renovated from existing buildings, there are many imperfections in design; therefore, temporary medical facilities cannot better meet the functional requirements of respiratory infectious disease treatment, and the medical environment inside is not people oriented enough. Subsequently, competent construction authorities of many provinces

in China have successively issued technical standards to guide the design and construction of temporary emergency medical facilities [1–11] in order to better respond to major public health emergencies in cities and to achieve the effective epidemic prevention goals of controlling the infection sources, cutting off infection chains, and hospitalizing and treating all such patients. At present, the cities that have used Fangcang shelter hospitals in China include Wuhan, Shanghai, Changchun, etc., and more other cities have reservation schemes for the construction of emergency Fangcang shelter hospitals, such as Guangzhou, Beijing, Shenzhen, Nanjing, Hangzhou, etc. However, the reservation schemes are generally superficial, and most of them are in the stage of the primary design of functional zoning and circulation organizing. Therefore, it is necessary to strengthen the guiding role of relevant technical standards in the construction of temporary medical facilities in the context of the persistence of the epidemic. Such a measure is conducive to the domestic standards and norms to learn from each other's strong points to offset their weaknesses, and to detect omissions and fill gaps in order to enhance the completeness and practicality of professional technologies.

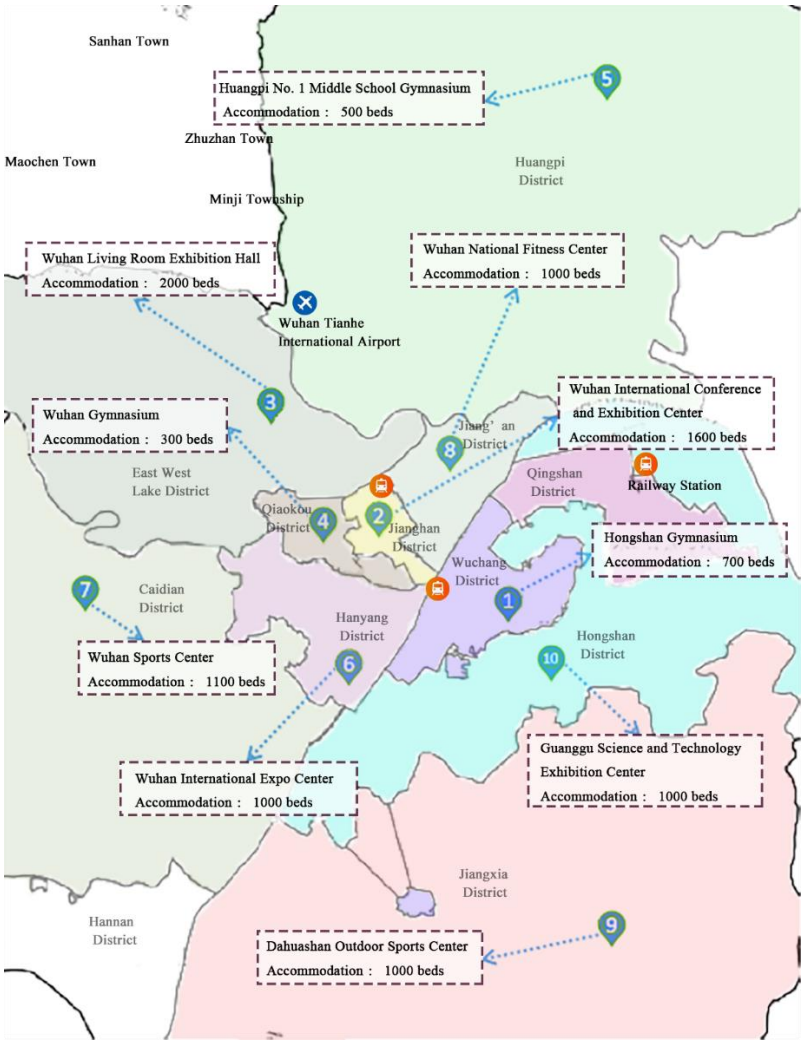

Figure 1. Distribution of Fangcang shelter hospitals in Wuhan during the COVID-19 epidemic. **Note: the order of numbers coincides with the opening time of Fangcang shelter hospitals**.

At present, global COVID-19 cases occur frequently and gather locally, of which more than 40% are concentrated in the neighboring countries and regions of China. The pressure of preventing imported COVID-19 continues to increase, and the local epidemic develops and changes rapidly [12]. Since February 2022, Hong Kong, Shanghai, Jilin and

other provinces have faced severe and complex prevention and control of the epidemic, dominated by Omicron mutant strains in many places at the same time. Accordingly, the Joint Prevention and Control Mechanism of the State Council issued an emergency notice, requiring all provinces, cities and autonomous regions to reserve Fangcang shelter hospitals according to the situation of the epidemic, to ensure that there are at least two to three Fangcang shelter hospitals ready (isolation sites) to respond to the changes in the epidemic [13], and to strive to maximize the prevention and control effect at the least cost.

Due to the persistence and uncertainty of the epidemic, the corresponding technical standards are required to guide the deployment and construction of the emergency medical facilities for better applications in epidemic prevention and control. This study aims to comprehensively compare the existing technical standards issued in China, to summarize their similarities and differences, to refine the key technologies, and to propose some suggestions to overcome shortcomings, thus making technical standards more effective in guiding the construction of emergency medical facilities. To achieve this goal, an in-depth comparison on the detailed regulations and terms between the existing 11 sets of technical standards are conducted. Moreover, both the similarities and disparities are summarized. Then, the primary contents of these technical standards include the site selection and architectural design, HVAC, structural design, electricity intelligence, water supply and drainage, operation and maintenance, environmental hygiene and safety, and fire protection. All these items are analyzed in-depth from the perspective of infectious disease control and health safety. Some key technical principles are concluded as well. Finally, the characteristics of existing technical standards are summarized from five aspects: restraint type, degree of perfection, combination of normal and emergencies, degree of infection control and graphic illustration. The suggestions for further optimization of the technical standards are also proposed from three aspects: interdisciplinary, post-use evaluation and cross-regional or transnational communication.

2. Overview of the Technical Standards

At present, the following 11 sets of technical standards for the design and construction of temporary treatment sites for COVID-19 have been published in China, as shown in Table 1. The abbreviations shown in the table are used to represent the corresponding technical standards in the following sections. These technical standards were made by the relevant building construction authorities in a short time. All of them had been approved and implemented immediately by the governments.

Table 1. Overview of the technical standards for emergency medical facilities.

No.	Title	Abbreviation	Main Content	Launch Time	Department in Charge
[1]	Technical Requirements for the Design and Conversion of Makeshift (FangCang) Hospitals (Revised Edition)	Hubei's Technical Requirements	• Selection of the building for renovation; • The necessary items for renovation; • Plan layout and quarantine requirements (three zones and two routes, sanitary passage, ward area, auxiliary room, barrier-free design); • Structural safety and on-site construction; • Water supply and drainage; electrical system; and heating, ventilation and air conditioning (HVAC); • Disinfection, sterilization and waste treatment.	February 2020	Department of Housing and Urban–Rural Development of Hubei Province

Table 1. *Cont.*

No.	Title	Abbreviation	Main Content	Launch Time	Department in Charge
[2]	Technical Guidelines for the Design and Conversion of Makeshift (FangCang) Centralized Treatment Hospitals (Trial version)	Zhejiang's Technical Guidelines	• Selection of the site location of the existing building for conversion; • Plan layout and quarantine requirements (two zones and two routes, sanitary passage, ward area, auxiliary room, barrier-free design); • Structural design and construction; • Water supply and drainage, electrical system and HVAC; • Health and safety; • Reference graphic cases of renovation.	February 2020	Department of Housing and Urban–Rural Development of Zhejiang Province
[3]	Design Guideline for the Emergency Transformation of Gymnasiums into Temporary Medical Center	Jiangsu's Design Guideline	• Key points of the existing gymnasium renovation; • Architectural design (functional zoning, route organization, logo, barrier-free design, fire protection design); • Key technologies of the structure and construction, water supply and drainage, HVAC and electricity intelligence; • Reference graphic cases of renovation.	February 2020	Department of Housing and Urban–Rural Development of Jiangsu Province
[4]	Design Guidelines for Emergency Treatment Facilities for COVID-19	NHC's Emergency Design Guidelines	• Selection of the site location; • Plan layout design; • Structural safety conditions; • Key technologies of the water supply and drainage, electrical system, HVAC and electricity intelligence.	February 2020	National Health Commission
[5]	Technical Standards for Buildings of Mobile Cabin Hospitals (Exposure draft)	Hebei's Technical Standard	• Application scope and site selection of the existing building for conversion; • Architectural design procedures; • Plan layout and quarantine requirements (three zones and two routes, sanitary passage, ward area, temporary treatment zone for severe cases, auxiliary room, barrier-free design); • Structural safety and design; • Water supply and drainage, electricity intelligence and HVAC; • Disinfection, sterilization and wastewater treatment; • Fire protection and emergency evacuation.	September 2020	Department of Housing and Urban–Rural Development of Hebei Province

Table 1. *Cont.*

No.	Title	Abbreviation	Main Content	Launch Time	Department in Charge
[6]	Design Guidelines for the Conversion of Existing Large Public Buildings for Both Peacetime and Wartime	Hubei's Design Guidelines for Existing Buildings	• Application scope and selection of the existing building for conversion; • Plan layout (three zones and two routes, sanitary passage, ward area, auxiliary room, barrier-free design) and medical treatment procedures; • Structural safety and design; • Water supply and drainage, electricity intelligence and HVAC; • Disinfection, sterilization and wastewater treatment.	November 2020	Department of Housing and Urban–Rural Development of Hubei Province
[7]	Design Guidelines for the Construction of New Large Public Buildings for Both Peacetime and Wartime	Hubei's Design Guidelines for New Buildings	• Selection of the site location; • Plan layout (three zones and two routes, sanitary passage, ward area, auxiliary room, barrier-free design); • Construction completion acceptance; • Structural safety and design; • Water supply and drainage, electricity intelligence and HVAC; • Disinfection, sterilization and medical gases.	November 2020	Department of Housing and Urban–Rural Development of Hubei Province
[8]	Design Guidelines for the Conversion of Fangcang Temporary Emergency Medical Treatment Facilities (Trial Version)	Shandong's Design Guidelines	• Selection of the site location of the existing building for conversion; • Plan layout and quarantine requirements (three zones and two routes, sanitary passage, ward area, auxiliary room, barrier-free design); • Structural safety and design; • Water supply and drainage, electricity intelligence and HVAC; • Fire protection and evacuation, garbage collection, and sewage treatment.	December 2020	Housing and Urban–Rural Development Department of Shandong Province
[9]	Specification for the Design of Large-Scale Public Facilities for Both Peacetime and Wartime	Hubei's Design Specification	• Application scope and site selection of the existing building for conversion; • Plan layout (three zones and two routes, sanitary passage, ward area, auxiliary room, barrier-free design) and medical treatment procedures; • Structural safety and design; • Water supply and drainage, electricity intelligence and HVAC; • Fire protection and evacuation, disinfection and sterilization, and sewage treatment.	March 2021	Department of Housing and Urban–Rural Development of Hubei Province

Table 1. *Cont.*

No.	Title	Abbreviation	Main Content	Launch Time	Department in Charge
[10]	Design Guidelines for Temporary Medical Quarantine and Observation Facilities (Trial version)	NHC's Temporary Design Guidelines	• Selection of the site location; • Plan layout and quarantine requirements (functional zoning, sanitary passage, ward area); • Structural safety and design; • Water supply and drainage, electricity intelligence and HVAC.	May 2021	National Health Commission
[11]	Design Guidelines for Fangcang Shelter Hospitals (Emergency Conversion of Temporary Centralized Quarantine Facilities) (Trial Version)	Beijing's Design Guidelines	• Site selection and key points of planning design; • Evaluation and key points of architectural design; • Structural safety and design; • Water supply and drainage, electricity intelligence, HVAC, fire protection and medical technology.	March 2022	Beijing Institute of Architectural Design

2.1. The Emergence of Technical Standards since the Outbreak of the Pandemic

Under the rapid spread of COVID-19 around the world, in comparison with other countries, China has taken a leading role in exploring issues about the construction of emergency medical facilities for patients of COVID-19. As the pandemic ravaged around the world in the first half year of 2020, technical manuals for the construction and operation of Fangcang shelter hospitals and COVID-19 emergency hospitals in Chinese versions were translated into more than 20 languages [14,15], providing significant references for many countries in front of the spreading of COVID-19. Later, Chinese experts, as the main participants, assisted the International Standards Organization (ISO) to complete the mission of compiling guidelines for the design and construction of emergency facilities against the epidemic [16]. After the COVID-19 epidemic was declared a global public health emergency at the end of January 2020, the World Health Organization (WHO) launched a practical manual for establishing and managing severe acute respiratory infection treatment centers [17]. In addition, the United States and Argentina successively launched their own technical standards [18,19] in addition to the anti-epidemic knowledge of China. All countries have made extraordinary efforts to build better emergency medical facilities. Based on the comparative analysis of these 11 sets of technical standards issued in China, this paper summarizes the similarities, differences and shortcomings and proposes more reasonable and feasible optimization suggestions on the amendment of these standards for further improvement in the renovation of Fangcang shelter hospitals and construction of new emergency medical facilities.

2.2. Formulation Thoughts of the Technical Standards

The formulation background and objectives of these technical standards are consistent with each other, all of which have been launched for the urban pandemic prevention and health and safety protection of residents. All of them take relevant regulations of Chinese national standards as reference, including the *Code for the Design of Infectious Diseases Hospitals* (GB50849-2014) [20], the *Construction Standards for Infectious Diseases Hospitals* (173–2016) [21], the *Code for the Design of General Hospitals* (GB51039-2014) [22], etc. Thus, these technical standards have similar structures and nearly the same contents in key clauses. However, their footholds and specific regulations have certain differences. The text mining method can highlight high-frequency professional words in these technical standards in a visual representation. As shown in Figure 2, the words of "Building, Contam-

inated area, Renovation, Medical, Design, Patient, Hospital, Clean, Disinfect, Facility" were selected as the top ten terms with the highest frequency by using a text mining tool known as a *Word Cloud*. Based on the results, it can be seen that the core points of decontamination and infection control are still the focus of the construction of emergency medical facilities during the treatment of infectious diseases. The conversion of existing buildings into temporary accommodations for patients is also a key measure that is used to deal with the epidemic.

Figure 2. High-frequency words of the 11 sets of issued technical standards.

It can be also found that the technical standards [5–11] launched in the later period generally consulted the relevant contents of previous standards to a certain extent and include more specific and detailed descriptions about the key technical regulation items. The differences in the formulation thoughts of the technical standards are mainly demonstrated as follows.

The NHC's *Emergency Design Guidelines* [4] and *Temporary Design Guidelines* [10] are the technical standards for public health emergencies at the national level. In comparison with the other nine provincial standards, they have a more extensive scope of application and show relatively stronger universality and orientation. Although the NHC's *Emergency Design Guidelines* [4] formulate relatively specific design regulations for new emergency hospitals and negative pressure wards, it does not provide any regulations for critical design techniques and requirements for the renovation of the existing buildings. In contrast, Hebei's *Technical Standard* [5] initiates more detailed technical regulations about the design of buildings and electrical systems. Moreover, it has also provided a detailed description and explanation for important terms and conditions.

In addition to the comprehensive contents and explicit structures for existing buildings, the technical standards of Zhejiang, Jiangsu and Shandong provinces [2,3,8] formulate more explicit regulations and restrictions on relevant terms. Specifically, these standards provide design codes for the conversion of Fangcang shelter hospitals and case studies on existing large space buildings (mainly including exhibition halls and gymnasiums) for reference. Detailed technical drawings of the reference cases are also given for better readability and higher reference value. It is worth mentioning that the NHC's *Emergency Design Guidelines* [4] are also illustrated, but it is for newly built emergency infectious disease hospitals. The application of the conversion of existing buildings to Fangcang

shelter hospitals is limited to gymnasium by Jiangsu's *Design Guideline* [3], and the graphic illustrations on the reference cases are clear and explicit. Accordingly, we have successfully converted the gymnasium of Guangdong University of Technology into a 300-bed Fangcang shelter hospital to prepare for large-scale COVID-19 infections in campus. As shown in Figure 3, the gymnasium after the conversion performs well regarding the clean–dirty partition and staff–patient division. The conversion from normal mode to emergency mode can be completed within 24 h. Thus, these technical standards play an exceptional demonstration role in practical renovation work.

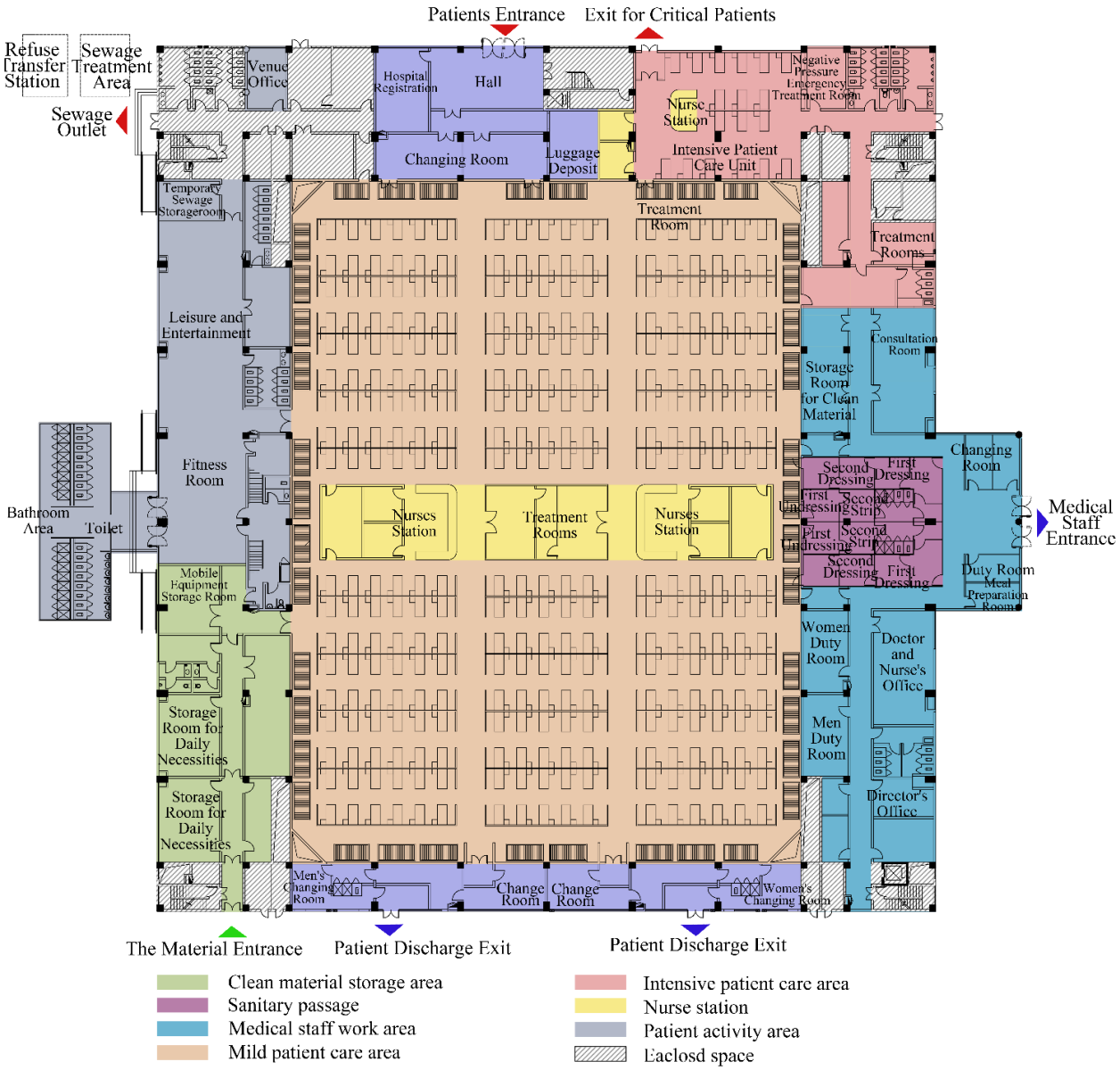

Figure 3. Fangcang shelter hospital renovated from a gymnasium of a university in Guangzhou by the authors.

Moreover, Hubei's *Design Specification* [9] is the combined version of the *Design Guidelines for Existing Buildings* [6] and *New Buildings* [7], which integrates the design principles and key terms of the two standards into the acceptance standards for the construction of large public buildings for the use of emergency medical sites.

Furthermore, except for the NHC's *Emergency Design Guidelines* [4] and *Temporary Design Guidelines* [10] as well as Hubei's *Design Guidelines for New Buildings* [7], which define

the technical restrictions for newly built emergency medical facilities, all the other standards focus on the technical regulations for the conversion of buildings into Fangcang shelter hospitals. NHC's *Emergency Design Guidelines* [4] only indicate the outline of the design principles and emphasizes the fundamental regulations for newly built emergency medical facilities which need to be quickly designed and constructed, such as the Huoshenshan Hospital and Leishenshan Hospital, constructed during the outbreak of COVID-19 in Wuhan, and Xiaotangshan Hospital, constructed in Beijing during the outbreak of SARS in 2003 [23]. Since new variants of the COVID-19 virus unpredictably and occasionally break out, hotels and public rental housings designated for medical quarantine and observation cannot meet the demands of surging numbers of potential patients, which has urged the release of NHC's *Temporary Design Guidelines* [10].

3. Comparison and Discussion

3.1. Key Items Involved in These Standards

According to the analysis on these 11 sets of technical standards, the main contents involve technical regulations of temporary medical facilities in terms of architectural design, structures, water supply and drainage, HVAC and electrical systems. Some other items, such as intelligent design, operation and maintenance, environmental hygiene and safety, fire protection, medical gases and construction requirements, are also specified in these technical standards in various degrees. Some of them are described separately, whereas some are integrated into other key items, and some parallel items are synthetically illustrated. However, most of the standards focus on the general regulations instead of detailed and applicable items. Only a few provincial technical standards refer to some special items, which are also important. For example, Jiangsu's *Design Guideline* [3] includes the content of the construction budget; Hubei's *Design Guidelines for Existing Buildings* [6] and *New Buildings* [7] specify the principles of interior design and decoration; and Shandong's *Design Guidelines* [8] set a separate chapter to demonstrate the application of innovative technologies.

According to the statistics, the main contents of these technical standards include eight key items, including the site selection and architectural design, HVAC, structural design, electricity intelligence, water supply and drainage, operation and maintenance, environmental hygiene and safety, and fire protection. According to the weighted proportion of each item in the issued technical standards, as shown in Figure 4, there are four items with larger weight values, including the site selection and architectural design, HVAC, electricity intelligence, and the water supply and drainage.

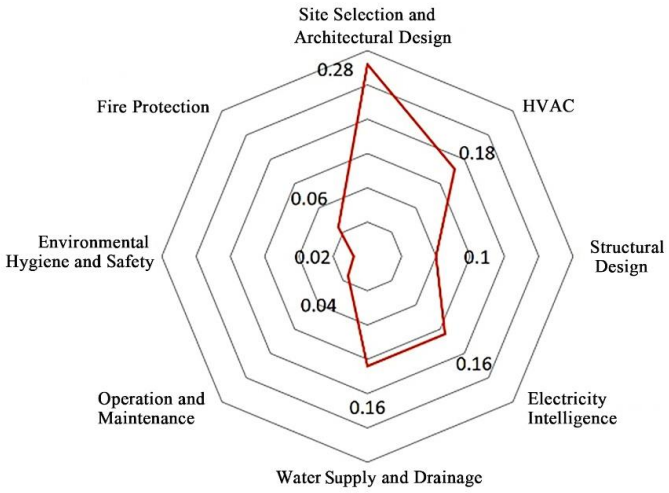

Figure 4. Weights of the main contents of the existing technical standards.

3.2. Site Selection and Architectural Design Based on Infection Control

Upon the outbreak of any public health emergency as a result of severe infectious diseases, the primary challenge faced by the government is to put infected people in

quarantine for treatment as quickly as possible according to the current policy of China, such as controlling the source of infection, cutting the chain of infection and protecting the susceptible population. Once the number of infections soars, the existing medical resources are usually in short supply. In this case, setting up emergency medical facilities is an important and effective way to solve the urban public health crisis. The government should promptly take countermeasures to find suitable sites for newly built emergency medical facilities and should choose the right existing public buildings for the conversion of temporary transitional facilities. By comparing the technical standards, it can be found that the requirements for the selection of the appropriate site and existing building is basically consistent. The detailed regulations are summarized in Table 2.

Table 2. Detailed requirements for the selection of an appropriate site and existing building.

Requirements for the Site Selection	Requirements for the Existing Building Selection
Certain protective distance from surrounding buildings	Large capacity of indoor space
Convenient access to urban roads	Multiple exits
Good municipal infrastructure	Safety
Wide open outdoor space	Internal passages available for barrier-free renovation

Source: Sorted by the authors according to the literatures [1–11].

Regarding the architectural design, NHC's *Emergency Design Guidelines* [4] and Hubei's *Design Guidelines for New Buildings* [7] primarily present a series of technical restrictions for newly built emergency medical facilities. However, there are few quantitative specifications on the architectural design. In contrast, the part of architectural design stated in Hebei's *Technical Standard* [5] is the most specific and systematic, which explicitly covers the sections of hospitalization, medical technology, medical matters, and material supplements. Hence, it shows greater pertinence in guiding the practices. Shandong's *Design Guidelines* [8] come second in regulating the architectural design. In particular, the detailed elaborations on the operation procedures of emergency medical facilities and the cleaning procedures for medical staff show great reference value for the design in practice. The items referring to the architectural design in both standards provide plenty of quantitative indicators, most of which are given based on the existing design codes for medical buildings. In addition, although the title words of "Fangcang shelters" in these two technical standards indicate their applicability in the conversion of existing buildings, many of the detailed regulations are also applicable to the design of new buildings.

It is worth noting that all these 11 sets of technical standards clearly set the design principles of the clean–dirty partition and staff–patient division for the medical environment of emergency medical facilities. Zhejiang's *Technical Guidelines* [2], for instance, require "two-zone, two-passage", embodied as polluted and clean zones, and as passages for patients and staff. In comparison, the requirement of "three-zone, two-passage", which includes the semi-polluted zone, has been adopted by all the other technical standards.

Although the architectural design parts in various technical standards are similar in their general principles, the specific terms have quite different emphases. The disparities in various regulations are shown in Table 3. It can be concluded that there are four key terms related to the architectural design and emphasized by all these technical standards, including the clean–dirty partition, nursing area, auxiliary rooms and evacuation design. The weights of these four terms in each standard are shown in Figure 5. It is worth mentioning here that the public space for social activities in temporary medical facilities is conducive to creating a comfortable and open environment for healing, which can significantly promote the recovery of infected patients [24]. However, elaboration on the design of public social spaces in emergency medical facilities is the most insufficient for all the technical standards.

Table 3. Comparison of existing technical standards in terms of architectural design.

		[1] Hubei	[2] Zhejiang	[3] Jiangsu	[4] NHC	[5] Hebei	[6] Hubei	[7] Hubei	[8] Shandong	[9] Hubei	[10] NHC	[11] Beijing
Functional rooms	Clean area	•	◐	◐	○	•	•	◐	•	•	◐	◐
	Semi-polluted area	•	○	•	○	•	•	○	•	•	◐	◐
	Polluted area	•	◐	•	○	•	•	◐	•	•	◐	◐
Personnel routes	Staff–patient division	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐	◐
Logistics routes	Clean-dirty partition	◐	○	◐	◐	◐	◐	○	◐	◐	○	◐
Transition between clean and dirty zones	Hygienic pass-through	○	◐	•	○	•	◐	◐	•	•	◐	◐
Wards and nursing area	Gender division	◐	○	○	○	◐	◐	○	◐	◐	○	○
	Number of beds	◐	◐	•	○	•	◐	◐	◐	•	◐	◐
	Bed spacing control	◐	◐	◐	○	•	◐	◐	◐	•	◐	○
Bathrooms and toilets		•	◐	•	○	•	•	◐	◐	•	◐	◐
Other auxiliary rooms		•	•	◐	○	•	•	•	◐	•	○	◐
Social activities		○	○	○	○	◐	○	○	○	◐	◐	○
Barrier-free design		◐	◐	◐	○	◐	◐	◐	◐	◐	○	○
Fire protection design		•	•	•	○	•	◐	•	•	•	○	◐
Logo design		◐	◐	•	○	◐	◐	◐	○	◐	○	○
Prefabricated construction		○	◐	○	◐	○	◐	◐	○	◐	◐	◐
Mechanical and electrical equipment		○	◐	○	◐	○	◐	◐	○	◐	◐	◐
Construction materials		○	○	○	◐	○	◐	○	○	◐	◐	◐

(Note: • indicates the availability of detailed regulations; ◐ indicates the availability of general regulations; ○ indicates the absence of regulations or very limited regulations). Data Source: Sorted by the authors according to the literatures [1–11].

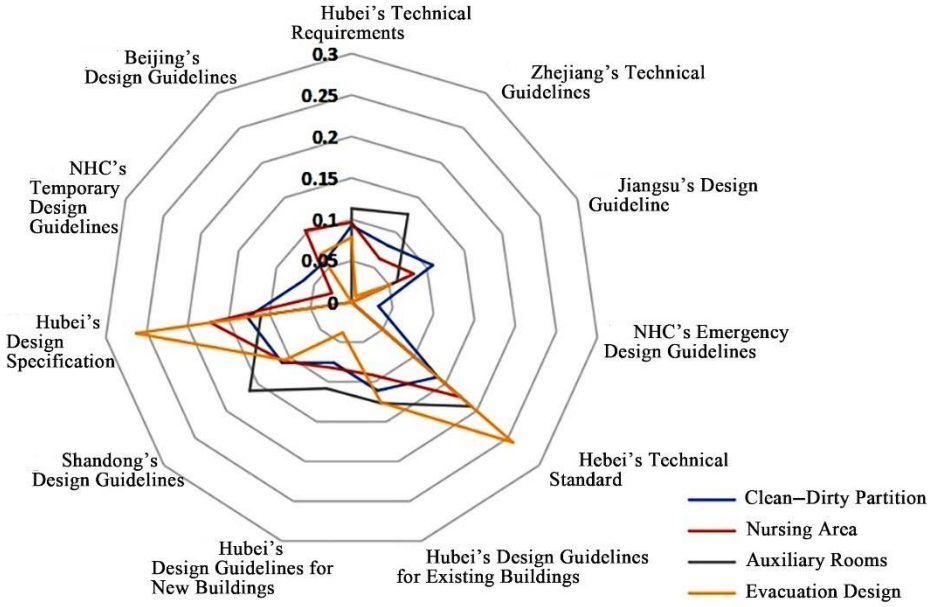

Figure 5. Weights of the key terms of architectural design in existing technical standards. Data Source: analyzed by the author according to literatures [1–11].

Infection control is a key technology in the treatment of infectious diseases. The appropriate design of the hygienic pass-through between the clean area and polluted area is essential to reduce the risk of infection for medical staff. Normally, the space

for the hygienic pass-through consists of a series of small functional rooms in which the pressure difference can ensure clean air flow from the clean area to the polluted area. The medical staff change protective clothing twice and pass through the buffer zone during the movement from the clean area to the polluted area. On the other hand, they must pass through buffer zones and take off protective clothing twice correspondingly during their return from the polluted area. The key issue is that the current technical standards fail to reach a consensus on the design codes of the hygienic pass-through between the clean area and polluted area. Significant disparities still exist in both the cognitions and practices. For instance, Zhejiang's *Technical Guidelines* [2] and Hebei's *Technical Standard* [5] do not have any requirement of setting buffer zones before the first undressing on the route from the polluted area to clean area. In addition, Shandong's *Design Guidelines* [8] present professional requirements for a hygienic pass-through to avoid cross-infection. It is easy to follow these design codes in newly built buildings, whereas many problems can emerge during the conversion of existing buildings. In comparison to other technical standards, the strictest regulation on the design of the hygiene pass-through is found in Hubei's *Design Specification* [9], which places particular emphasis on the requirement of setting a buffer room between two undressing rooms for the safety consideration. The reason for this requirement is to prevent the medical staff from breathing in potentially polluted air from the first undressing room while removing the mask in the second undressing room (Figure 6), which can possibly further reduce the risk of infection. However, all these technical standards lack quantitative specifications on the design of the hygienic pass-through in terms of the minimum area of the functional room and buffer room, as well as the minimum number of showers and toilets.

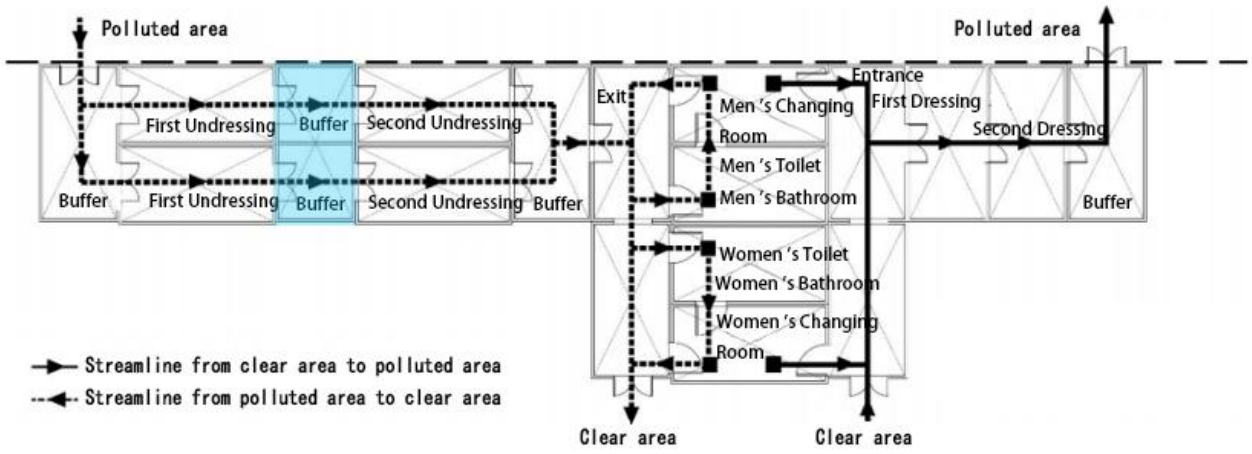

Figure 6. Regulation of the hygienic pass-through design in Hubei's *Design Specification* [9].

3.3. Design of HVAC, Electricity and Intelligence, and Water Supply and Drainage for Sanition

As professional medical facilities for treating and curing patients with respiratory infectious diseases, HVAC design is a key point. All the above technical standards present explicit design codes for the indoor air ventilation and air conditioning system in emergency medical facilities. The details are listed in Table 4. The solutions of ventilation design, such as the air distribution, fresh air exchange and air filtration, are summarized as follows:

(1) Controlling the air pressures in different zones to ensure that the air flows from the clean area to the polluted area;
(2) Controlling the frequency of fresh air exchange and appropriately diluting the virus concentration in the wards;
(3) Controlling the cleanliness of indoor air through disinfection and sterilization.

Table 4. Comparisons of regulations of ventilation and air conditioning.

	[1] Hubei	[2] Zhejiang	[3] Jiangsu	[4] NHC	[5] Hebei	[6] Hubei	[7] Hubei	[8] Shandong	[9] Hubei	[10] NHC	[11] Beijing
Air distribution	√	√	√	√	√	√	√	√	√	√	—
Air pressure control	√	√	√	√	√	√	√	√	√	√	—
Air filter	√	√	√	√	√	√	√	√	√	—	—
Air disinfection and sterilization	—	√	√	—	√	—	√	√	√	√	√
Air conditioning	√	√	√	√	√	√	√	√	√	√	√
Indoor temperature control	—	√	√	—	√	√	√	—	√	√	√
Condensate treatment	—	√	—	√	√	√	√	√	√	√	√
Fire smoke prevention and exhaust	—	—	√	—	—	—	—	—	—	—	—

(Note: √ represents the presence of the regulations,—indicates the absence of this regulation). Data Source: sorted by the author according to literatures [1–11].

It is necessary to note that the air conditioning system should be applied in the clean area and the polluted area. In addition, the exhaust ducts and condensate water in the polluted area need to be disinfected. It is also suggested that the air-conditioning system should keep running throughout the day to ensure the maximum intake of fresh air. Regarding the conversion of existing buildings, although it is encouraged to utilize the existing air-conditioning system, necessary retrofitting should be made based on the above strict sanitary requirements for the HVAC system.

Furthermore, existing regulations on HVAC in these technical standards seldom refer to the fire smoke control and extraction. Only the Jiangsu's *Design Guideline* [3] mentions that the solution of fire smoke control and extraction should comply with the current fire protection design codes, which a few standards have simply stated.

Regarding the electricity and intelligence system, the related regulations are included in all the existing technical standards, with an agreement on the principles of safety, reliability and convenience. The technical regulations of the electricity system mainly involve the power supply and distribution, lighting, pipeline installation, etc. Among all the existing standards, the design regulations referring to the electricity system proposed by Hebei's *Technical Standard* [5] are the most explicit and specific, whereas those in NHC's *Emergency Design Guidelines* [4] are the most insufficient. It is worth noting that four of these standards, including Jiangsu's *Design Guideline* [3], Hebei's *Technical Standard* [5], NHC's *Temporary Design Guidelines* [10] and Beijing's *Design Guidelines* [11], separate the technical regulations of the intelligence system from the electricity system design as an independent special item, which may result in a higher reference value. On the other hand, the phenomenon of cross-ascription and overlap also exists in some technical standards. For instance, relevant regulations on emergence lighting are included as a part of the electricity system design instead of the fire protection design in Jiangsu's *Design Guideline* [3]. In addition, regulations on the medical robot, remote consultation, and building information modelling (BIM) system mentioned in the special item of the innovative technology applications in Shandong's *Design Guidelines* [8] should essentially fall within the scope of electricity and intelligence system design.

Furthermore, the item of water supply and drainage system design mainly refers to the relevant regulations in the existing architectural design codes of infectious disease hospitals, which have strong principles and universality. In comparison with other technical standards, the regulations on this item show finer classifications and comprehensive contents in three existing standards, including Jiangsu's *Design Guideline* [3], Hebei's *Technical Standard* [5] and Hubei's *Design Guidelines for Existing Buildings* [6]. It is necessary

to note that the drainage design is generally more detailed and regulated than the water supply design, mainly focusing on the wastewater and condensate water discharge and sewage treatment in polluted zones. Some provincial standards, such as Shandong's *Design Guidelines* [8], even separate the regulations on sewage treatment as an independent item, which shows the significance. In addition, most existing standards mention the design codes of hot water supply for emergency medical facilities, but all the terms are similar and lack in-depth descriptions.

3.4. Regulations on the Other Items Aiming at Safety

All the 11 sets of technical standards highlight the safety and reliability of the structural design and insist that both the conversion of existing buildings and the construction of new buildings should comply with the existing structural design codes. The relevant structural design regulations shown in most studied standards are the universal principles at the medium and macro levels, and only Hubei's *Design Guidelines for Existing Buildings* [6] includes specific requirements for the structural design from the foundation to the structure above the ground, as well as regulations on the structural construction.

Regarding the item of fire protection design, it is included in Hubei's *Technical Requirements* [1], Zhejiang's *Technical Guidelines* [2] and Hebei's *Technical Standard* [5], and it has been merged into the item of architectural design by all the other technical standards, embodied as the number of entrances and exits, the width of evacuation walkways, the evacuation index for one hundred people and other quantitative specifications.

The item of operation and maintenance is essential for the normal operation of emergency medical facilities. In comparison, regulations on this item are specifically proposed in detail in Hubei's *Design Guidelines for Existing Buildings* [6] and *New Buildings* [7], whereas those in other standards simply refer to the general requirements for HVAC, water and power supply, etc.

The item of environmental hygiene and safety in emergency medical facilities mainly involves the treatment of domestic garbage, medical waste and wastewater, which is included in a special chapter by Hubei's *Technical Requirements* [1], Zhejiang's *Technical Guidelines* [2], Hebei's *Technical Standard* [5] and Shandong's *Design Guidelines* [8]. Instead, most of these contents are merged into the item of operation and maintenance in the other seven technical standards, whereas only some general regulations on pollutant disposal and environment disinfection are formulated.

4. Conclusions

In this study, an in-depth analysis and comparison was conducted on the detailed regulations and terms among the existing 11 sets of technical standards. Both the similarities and disparities were concluded and highlighted.

Based on the above analysis, some essential conclusions can be drawn, as follows:

(1) The content of the technical standards formulated in later periods are generally more profound and mature than those issued in earlier stages. As the earliest technical standard, although its framework and key points show certain superficialness, Hubei's *Technical Requirements* [1] played a groundbreaking and meaningful role in guiding the formulations of technical standards launched in later periods.

(2) The Hubei's *Design Guidelines for Existing Buildings* [6] and *New Buildings* [7] successively formulated based on practical operation experiences show significant improvement in the depth of contents and system construction. Both of them elaborate in detail the regulations on the conversion of existing buildings and the construction of new buildings for both peacetime and emergencies.

(3) Both Hebei's *Technical Standard* [5] and Shandong's *Design Guidelines* [8] demonstrate greater depth in the formulation of architectural design regulations, which cover detailed qualitative and quantitative specifications in terms of cross-infection prevention and medical treatment procedures.

(4) Compared with the technical standards described in only text, those with graphic illustrations, such as Zhejiang's *Technical Guidelines* [2], Jiangsu's *Design Guideline* [3], NHC's *Emergency Design Guidelines* [4] and Shandong's *Design Guidelines* [8], exhibit better readability, which is very beneficial for an in-depth understanding of the practical application of critical technologies.

Generally, due to the imperfections and superficialness of the current versions of the existing technical standards, further improvement on the maturity and systematism is necessary. Based on above conclusions and to the best of our knowledge, the following suggestions are proposed for the amendment and optimization of the existing technical standards:

(1) Strengthen interdepartmental, cross-industrial and interdisciplinary cooperation to ensure the explicit expression of the compulsory requirements in the technical regulations issued by the building construction authorities.
(2) Improve the evaluation system of the performance of emergency medical facilities, such as surveying various people such as patients, medical staff, managers and volunteers and summarizing the main defects in the physical and psychological environments of existing emergency medical facilities.
(3) Strengthen cross-regional and international technical exchange and cooperation for the construction of emergency medical facilities. It is necessary to establish an open-data platform to share practical experiences and research findings on a real-time basis.

It is worth noting that the construction cost for new emergency medical facilities dedicated for pandemics is generally very high. It is usually difficult to guarantee the construction quality of projects completed in a short time. Hence, these facilities may fall into the dilemma of where to go after the pandemic [25], which arouses many arguments on the construction values of newly built emergency medical facilities. In comparison, by virtue of features such as short construction time, low cost and high accommodation capacity for patients, converting existing buildings into Fangcang shelter hospitals is an effective way to remit the shortage of medical resources, as well a main approach to improve the urban emergency medical system [26,27].

COVID-19 is not only a crisis, but also an opportunity. The construction of emergency medical facilities against severe infectious diseases has great significance for the urban public health security and safety of residents. "Preparedness ensures success and unpreparedness spells failure". The formulation of technical standards for temporary medical facilities is imperative against pandemics. However, we still have a long way to go for the improvement of such standards.

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