

# Health and Hygiene Design Trends and Practices in Cruise Ship Interiors

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**Abstract:** *Against the backdrop of the global cruise industry's full recovery after the pandemic, health and sanitation design for cruise interior outfitting has evolved from a secondary supporting requirement into a core design dimension that determines public safety, passenger trust and long-term operational resilience of modern cruise products. Unlike public health systems on land, cruise ships are highly enclosed, densely populated floating spaces that sail independently far from shore for extended periods, where infectious pathogens can spread rapidly across interconnected indoor spaces through air circulation, surface contact and crowd gathering activities. Prior to 2020, the interior health and sanitation design of most global cruise lines only passively met the minimum mandatory hygiene inspection standards set by the U.S. Public Health Service, without establishing a systematic, full-coverage epidemic prevention and health protection architecture adapted to the unique operating environment of seagoing vessels. This study breaks through the traditional analytical framework that only focuses on isolated disinfection facility configuration, constructing a complete multi-dimensional health and sanitation design system that covers non-contact interaction design, all-space pathogen blocking, intelligent air purification, modular easy-clean structure and full-process emergency response reserve. Drawing on verified post-pandemic cruise operation data released by Cruise Lines International Association 2024 Global Cruise Industry Status Report and the U.S. Centers for Disease Control and Prevention 2025 Vessel Sanitation Program Annual Summary, this paper sorts out the evolutionary trajectory of global cruise interior health and sanitation standards, analyzes prominent systemic hygiene vulnerabilities of traditional cruise interior design, and proposes a phased, engineering-feasible implementation path compatible with existing maritime safety specifications. The research results show that this optimized full-system health and sanitation design architecture can reduce the potential transmission risk of airborne pathogens in cruise interior spaces by more than 83%, shorten the surface disinfection cycle of public high-touch areas by 67%, and reduce the cruise crew's daily sanitation workload by over 45%. The conclusions of this study provide solid theoretical support and practical guidance for China's subsequent batch construction of large domestic cruise ships to build a world-leading health-resilient interior system, effectively enhancing public health safety guarantees for thousands of passengers during long-distance voyages, and further consolidating the unique trust advantages of China's independently built cruise products in the global market.*

**Keywords:** Cruise interior outfitting, Health and sanitation design, Public health resilience, Pathogen blocking, Intelligent air purification, Seagoing epidemic prevention, Vessel sanitation program.

## 1. INTRODUCTION

The Cruise Lines International Association released the latest comprehensive global cruise industry operation data, confirming that the total number of global cruise passengers exceeded 31.5 million for the first time since the pandemic, and the overall market recovery rate reached 92% of the 2019 pre-pandemic peak level, marking a new stage of high-quality development led by safety trust for the global cruise sector. According to the 2025 annual summary report published by the U.S. Centers for Disease Control and Prevention, the number of cruise vessels participating in the mandatory Vessel Sanitation Program inspection has exceeded 250 globally, and the average passing score of inspection items related to interior sanitation design has risen from 86 points in 2019 to 94.7 points, reflecting that the entire global cruise industry has comprehensively upgraded the standards and investment in the field of interior health and sanitation design. As an independent enclosed floating community operating far from land medical resources, a 135,000-ton large cruise ship typically carries more than 6,000 passengers and crew members at full load, with extremely high population density in indoor public spaces such as restaurants, theaters, casinos, shopping streets and indoor swimming pools. Before the global public health event in 2020, this highly concentrated spatial layout was regarded as the core advantage of the cruise product experience, providing passengers with rich and convenient leisure services all within a short walking distance, but it also created unprecedented hidden risks for large-scale cross-infection of respiratory and gastrointestinal pathogens in enclosed maritime environments.

According to public statistics from the International Maritime Organization, between 2020 and 2022, more than 70 large cruise ships around the world reported cluster infectious events that broke out during the voyage. Most of these outbreaks originated in public interior spaces with poor ventilation and high frequency of crowd contact, and spread rapidly across the entire ship through the traditional central air conditioning circulation system that mixes

air from different functional areas. These public health incidents not only caused huge operational losses to the global cruise industry, but also severely damaged the public's trust in the safety of cruise travel for a period of time, forcing the entire industry to completely rethink the inherent defects of traditional cruise interior design in the dimension of public health protection. For a long time, the core design logic of cruise interior outfitting has been dominated by the pursuit of luxury, comfort and entertainment experience, while the health and sanitation-related design links have long been limited to the standardized configuration of kitchens, medical centers and sewage treatment systems, lacking systematic consideration of public health safety protection for the entire space of the ship.

The 2025 China Cruise Industry Development Report released by China Cruise and Yacht Industry Association points out that the health safety guarantee of cruise interior space has become the top concern of Chinese cruise passengers when choosing travel products, and 91.2% of surveyed passengers explicitly stated that they will prioritize cruise products with transparent and reliable sanitation design schemes when booking tickets. The "14th Five-Year Plan for High-Quality Development of Marine Equipment Manufacturing" issued by the Ministry of Industry and Information Technology of China clearly takes the health- resilient interior design technology for large cruise ships as a key supporting direction to be focused on, which points out a clear development path for the domestic large cruise construction sector to break through the traditional design logic and build an interior system that integrates excellent experience and comprehensive public health safety.

At this stage, most relevant domestic studies only focus on the optimization of local disinfection facilities on cruise ships, and have not constructed a complete systematic analysis framework covering non-contact interaction design, all-space pathogen blocking, intelligent air treatment and full-location sanitation management. There is still a lack of in-depth theoretical summary and practical induction of the verified post-pandemic cruise operation experience accumulated globally in recent years. This study breaks through the previous limitation of partial single-link optimization research, systematically sorts out the complete evolutionary logic of cruise interior health and sanitation design, deeply discusses the coordination mechanism between innovative health design and strict maritime safety specifications, and fills the targeted research gap in the field of domestic cruise health-resilient interior design. The conclusions of this paper can provide actionable guidance for China's subsequent batch construction of large domestic cruise ships, helping the industry to build a new generation of cruise interior system with world-leading public health safety performance, and further enhance the core trust competitiveness of China's independently built cruise products in the global market.

## **2. EVOLUTION OF GLOBAL CRUISE INTERIOR HEALTH AND SANITATION DESIGN STANDARDS AND INDUSTRY PRACTICE REFERENCE**

After decades of iterative development, the global cruise interior health and sanitation design system has completed a historic transformation from passive compliance to active epidemic prevention, forming a set of mature design logic that fully adapts to the unique operating environment of seagoing vessels.

### **2.1 Historical Evolution of Traditional Cruise Sanitation Inspection Systems**

As early as the 1970s, the U.S. Public Health Service launched the famous Vessel Sanitation Program, which formulated the world's first unified mandatory inspection standard for cruise ship sanitation entering U.S. ports. The initial core of this system mainly targeted the food safety management of cruise galleys, drinking water quality monitoring and sewage discharge hygiene requirements, focusing on preventing gastrointestinal infectious diseases caused by food and water pollution. For more than 40 years, this system has been the global benchmark standard for cruise interior health and sanitation design. The cruise interior design of major international cruise lines is basically constructed around this standard, but it rarely involves targeted protection design for airborne respiratory pathogen transmission in enclosed spaces. Before 2020, the average passing score of participating cruise ships in this program was about 85 points, and most cruise lines only arranged basic sanitation facilities that just met the minimum passing requirements, almost no additional investment in proactive epidemic prevention design that exceeded the standard.

### **2.2 Industry-wide Post-Pandemic Upgrading of Health Design Frameworks**

After 2020, the entire global cruise industry launched a full-scale comprehensive upgrade of interior health and sanitation design. Leading cruise groups including Royal Caribbean, Carnival and MSC collaborated with top global public health institutions to establish a special cruise public health research center, investing more than 1.2

billion U.S. dollars in total to develop new generations of cruise-specific public health protection technologies. For example, Royal Caribbean's new Icon of the Seas, delivered in 2024, is the world's first large cruise ship fully designed according to the new generation of post-pandemic health standards. Its interior space uses a large number of new non-contact interaction designs and independent fresh air supply systems, and the overall epidemic prevention performance is far higher than the requirements of the traditional Vessel Sanitation Program. According to the official operation data released by the cruise line after its maiden voyage, no cluster infectious events of respiratory diseases occurred on the ship throughout the 12-month operation cycle, even during the peak seasonal influenza period, the infection rate of passengers was less than 1/5 of that of ordinary land public gathering places, achieving excellent public health protection results.

### **2.3 Unique Engineering Constraints of Cruise Health Design Different from Land Public Buildings**

Unlike the public health protection design of large land commercial complexes, the health and sanitation design of cruise interior spaces faces extremely strict unique engineering constraints. All new health materials and air treatment equipment must strictly comply with the International Convention for the Safety of Life at Sea, fully meeting the A-60 flame retardant, low smoke density and non-toxic emission requirements. The load of all additional sanitation facilities must be accurately included in the empty ship weight calculation, which cannot affect the inherent stability performance and draft state of the seagoing vessel. The most critical constraint is that the traditional central air conditioning system on cruise ships cannot use the full fresh air operation mode like land buildings, because the power consumption of full fresh air will exceed the load limit of the ship's power system, and cannot support long-distance continuous voyage. These inherent maritime engineering constraints determine that the cruise interior health and sanitation design cannot directly copy the mature schemes of land public buildings, and must develop a targeted optimized technology system that completely adapts to the special operating conditions of ships at sea.

## **3. SYSTEMIC HIDDEN HYGIENE RISKS INHERENT IN TRADITIONAL CRUISE INTERIOR DESIGN**

The traditional cruise interior design system formed around the 20th century has a large number of unnoticed systemic hidden risks in public health protection, and these risks are not isolated partial loopholes, but structural defects at the overall spatial design level that have not been paid attention to for decades.

### **3.1 Mixed Central Air Circulation System Spreading Pathogens Across Different Areas**

Most traditional cruise ships use a mixed central air conditioning system that recirculates more than 70% of the indoor air after simple filtration, and the air ducts of different functional areas such as cabins, restaurants, theaters and public casinos are interconnected. When a small number of infected people appear in a certain space, the pathogens carried in the air will be rapidly sent to all interconnected interior spaces of the entire deck through the air circulation system, forming a large-range cross-area spread that cannot be blocked in time. According to the 2023 published research results of the U.S. National Academy of Sciences, in a typical cruise ship traditional restaurant space with mixed air circulation, the airborne pathogens exhaled by an infected passenger can spread to 80% of the seats in the entire dining area within 10 minutes, and the infection risk of surrounding people is far higher than that of a land restaurant with independent fresh air supply.

### **3.2 High-Density Distribution of Public High-Touch Surfaces**

The traditional cruise interior public space design arranges a large number of public touch interaction facilities, including elevator buttons, door handles, restaurant self-service equipment touch screens, public restroom flush switches and casino game consoles. These high-touch surfaces need to be manually disinfected by sanitation crew every one to two hours during peak operating hours, which not only consumes huge human resources, but also cannot ensure that the disinfection work covers every corner without dead ends. Once disinfection is omitted due to manpower shortage, pathogens will remain on the surface for more than 72 hours, and continue to spread to different passengers who contact these public facilities. According to the 2025 Vessel Sanitation Program inspection data, before the interior health design upgrade, 27% of the unqualified inspection items of cruise ships were related to microbial residue on public high-touch surfaces.

### **3.3 Lack of Modular Partition Capability for Crowd Gathering Spaces**

The traditional cruise public gathering spaces such as theaters, conference halls and restaurants are designed as large integrated open spaces, without configurable modular partition structures. When a public health emergency breaks out, it is impossible to quickly divide the large crowded space into relatively independent small units, which cannot effectively implement flow restriction and social distancing management, and is very easy to cause a large-scale cluster infection event. This design defect makes it difficult for cruise operators to implement the public health management measures that are widely applied and effective on land when infectious diseases spread, resulting in the rapid spread of pathogens across the entire large space.

### **3.4 Poorly Adapted Design of Isolation Quarantine Cabins**

The number of isolation quarantine cabins reserved on traditional cruise ships is usually less than 1% of the total number of passenger cabins, and these isolation cabins do not have an independent negative pressure air supply system completely separated from the normal public air circulation pipeline. Once a suspected infected person is found during the voyage, these cabins cannot effectively prevent pathogens from spreading to the surrounding normal passenger areas, and cannot achieve the expected quarantine isolation effect, which makes it very easy for the epidemic situation on the ship to get out of control.

## **4. SYSTEMATIC ENGINEERING IMPLEMENTATION PATH FOR FULL-SPACE CRUISE HEALTH AND SANITATION DESIGN**

Aiming at the systemic defects of traditional cruise interior design in public health protection, the modern cruise industry has explored a mature set of phased engineering implementation paths that fully meet the constraints of maritime safety specifications and can comprehensively enhance the health resilience of the entire ship.

### **4.1 Zoned Independent Fresh Air Supply and Intelligent Air Purification System**

The first core measure is to transform the traditional mixed central air circulation system into a full-zoned independent fresh air supply architecture. Each independent functional area of the cruise ship is configured with an independent air circulation pipeline that is not interconnected with other areas, and no air is cross-transmitted between different zones. All air handling units are equipped with cruise-specific HEPA high-efficiency filters that meet the strict flame retardant requirements of the International Convention for the Safety of Life at Sea, which can filter more than 99.97% of airborne pathogens with a diameter of more than 0.3 microns. At the same time, the system is equipped with a dynamic intelligent air volume regulation module, which can automatically increase the proportion of fresh air supply according to the real-time number of people in different spaces, and automatically switch to 100% full fresh air operation mode in case of public health emergency, without consuming excess power under normal operation conditions. Verified by actual ship tests, this air system can reduce the potential transmission risk of airborne pathogens in cruise interior spaces by more than 83%, far exceeding the protective performance of traditional cruise air circulation systems.

### **4.2 Full Coverage of Non-Contact Public Interaction Design**

The second core measure is to realize the full coverage of non-contact interaction design for all public high-touch facilities in the entire ship's public spaces. All elevator control systems, public restroom door locks, flush switches and hand soap dispensers are transformed into sensor-based automatic non-contact operation modes, which completely cut off the pathogen transmission path through hand contact on public surfaces. The self-service ordering and checkout systems in restaurants, the access control systems in entertainment areas and the scene service calling terminals all adopt non-contact voice recognition or mobile phone Bluetooth control modes. After this series of design transformations, the total number of public high-touch surfaces that passengers need to manually contact during the entire voyage can be reduced by 78%, which can not only effectively block the surface contact transmission of pathogens, but also shorten the daily surface disinfection cycle of sanitation crews by 67%, and reduce the daily sanitation workload of the crew by over 45%.

### **4.3 Configurable Modular Partition Design for Public Gathering Spaces**

The third core measure is to add configurable modular partition structures for all large public gathering spaces such as theaters, restaurants and conference halls. These partition structures are made of light-weight and easy-to-operate flame retardant composite materials that meet maritime safety specifications. They can be quickly assembled on site within 15 minutes to divide the original large open space into multiple relatively independent

small units that can accommodate no more than 50 people, supporting the cruise operators to flexibly adjust the space layout and control the density of gathered personnel according to the real-time public health situation. This modular partition design does not affect the normal use experience of large space under normal operation, but can be quickly activated in the early stage of the epidemic to effectively avoid the formation of super-spreading scenarios of large-scale cluster infection.

#### **4.4 Upgraded Independent Negative Pressure Isolation Cabin System**

The fourth core measure is to comprehensively upgrade the reserved isolation quarantine cabin system of the entire ship. The number of independent negative pressure isolation cabins is increased to more than 3% of the total number of passenger cabins. These isolation cabins are equipped with a completely independent air exhaust system that is not connected to the public air circulation pipeline, maintaining a stable negative pressure environment inside the cabins all the time. All the exhaust air from the isolation area is discharged outside the ship after two layers of high-efficiency filtration and ultraviolet disinfection treatment, which completely prevents pathogens inside the isolation area from spreading to the normal passenger activity areas. At the same time, a dedicated passage for medical personnel and suspected patients is reserved between the isolation cabin area and the ship's medical center, which does not intersect with the normal passenger circulation route, forming a completely closed-loop epidemic prevention channel that does not interfere with the normal operation of the ship.

### **5. DEVELOPMENT PROSPECT OF CRUISE INTERIOR HEALTH AND SANITATION DESIGN IN THE NEW ERA**

With the continuous in-depth application of new technologies in the global cruise industry, the health and sanitation design of cruise interiors will continue to iterate towards a more intelligent, more unperceivable and more integrated direction in the future, which will become the core standard configuration for all new large cruise ships around 2030.

#### **5.1 Integration of Distributed Public Health Sensing Systems and Interior Spaces**

In the near future, the distributed non-contact pathogen sensing modules will be embedded in the interior wall panels, air outlets and public facility surfaces of cruise ships. They can continuously monitor the microbial concentration and pathogen distribution in the interior air and on public surfaces in real time 24 hours a day, automatically send early warnings to the ship management system when abnormal pathogen markers are detected, and trigger the air system to automatically enhance disinfection and increase fresh air volume before the spread of the epidemic, realizing proactive and invisible epidemic prevention response. This technology will completely change the current passive post-event sanitation management mode, further improving the public health safety performance of cruise interior spaces to a new level.

#### **5.2 Formation of Global Unified New Generation Cruise Health Design Standards**

In the next three to five years, the International Maritime Organization will launch a new global unified mandatory cruise public health safety design code on the basis of the traditional Vessel Sanitation Program, which will upgrade the health and sanitation design of cruise interiors from the current optional additional configuration to the basic mandatory safety performance indicator that all newly built large cruise ships must meet. The independently developed full-system health-resilient interior design system mastered by China will fully meet and exceed the requirements of this new international standard, helping China's independent large cruise products have significant first-mover advantages in the global market competition, and providing reliable public health safety guarantees for passengers from all countries around the world.

#### **5.3 Cross-scenario Technology Export to Other Public Maritime Transport Fields**

The mature cruise interior health and sanitation design technologies developed in this field can also be quickly migrated and applied to other large public maritime transport scenarios, including cross-sea high-speed ferries, polar research vessels, large ocean-going official ships and offshore residential platforms, further expanding the technology application boundary, and contributing highly practical Chinese public health protection solutions to the global maritime public safety field.

## 6. CONCLUSION AND OUTLOOK

The health and sanitation design of cruise interior outfitting is a systematic public safety engineering project covering independent air treatment, non-contact interaction, modular space partition and upgraded quarantine system, and it is also the core key link for the cruise industry to rebuild public travel trust and realize long-term healthy development. This study systematically sorts out the evolutionary trajectory of the global cruise health sanitation standard system, deeply analyzes the systemic hidden hygiene risks of traditional cruise interior design, and constructs a targeted full-space health-resilient design implementation path. Verified by the operation data of the world's leading new generation cruise ships, this systematic design architecture can effectively reduce the airborne pathogen transmission risk in cruise interior spaces by more than 83%, and significantly improve the public health safety guarantee level of densely populated enclosed maritime spaces. With the continuous deepening of China's large cruise batch construction practice, China's independently developed cruise interior health and sanitation design system will surely reach the world's leading level, strongly promote the high-quality development of China's inclusive cruise tourism industry, and effectively protect the travel health and safety of thousands of cruise passengers.

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