Journal of Engineering and Applied Research (JEAR)

National University of Skill

Winter & Spring 2026, Vol. 3, No. 1, p. 181-192

Journal Homepage: https://jear.tvu.ac.ir

: 10.48301/jear.2024.479643.1046

Ventilation, air disinfection and purification system`s design for elevators of medical centers

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ARTICLE INFO

Article Type:
Original Research

Received: 2024.09.24
Revised:
Accepted: 2024.11.03

Keyword:
Air disinfection and purification-system
Elevators
Medical centers
Pollution emission
Filtration.

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ABSTRACT

At present time, hospitals and treatment centers are one of the most important places where people travel to receive health and treatment services in different countries of the world. But in some cases, the process of providing services by these centers inevitably leads to the transmission and spread and epidemic of diseases between people. This can even be life-threatening for some patients with vulnerable conditions. So, considering the sensitivity of the transmission of diseases between people and the risks of life threatening, the use of proper ventilation and air purification systems in medical centers, especially indoor and closed spaces such as elevators, where people gather in these spaces without observing social distance, can be help prevent the chain spread of diseases. Therefore, considering the existence of microorganisms in hospital environment, this paper, concentrated on designing a suitable ventilation system especially for air disinfection and purification in the elevators in hospital and medical centers.

E-ISSN: 3060-6357

Introduction

Studies indicate that approximately 5 to 10 percent of patients admitted to intensive care units acquire one or more types of infections. On the other hand, the issue of infection transmission and spread in hospitals among patients has steadily increased over the past decades. These infections affect about 2 million people annually in the United States and result in approximately 90,000 deaths. This issue adds about 4.5 to 5.7 billion dollars per year to the cost of patient care in hospitals [1]. Therefore, controlling hospital-acquired infections has a significant impact on the safety and health of patients.

One of the ways infections and viruses spread among individuals in healthcare facilities is through airborne transmission. This includes various factors present in hospitals such as fungi, bacteria, and viruses, which can move through different parts of the hospital via dust carried by air. Consequently, this creates a pathway for diseases and microorganisms to spread among patients and those under treatment [2]. Therefore, establishing air purification and ventilation systems in these facilities will help prevent the spread of microorganisms among patients and their transmission to close contacts and more broadly in the community.

Research and studies indicate that airborne disease transmission in hospitals is a significant risk for infecting patients, staff, and visitors. Therefore, methods of airborne disease transmission and the factors influencing this transmission have been examined. The main sources of airborne disease transmission in hospitals include particles shed by infected patients. The most critical factors influencing airborne disease transmission include wind speed, the concentration of particles shed by patients, and particle size. Additionally, the type of virus or bacteria and its ability to survive in the air and on contaminated particles can be factors in disease spread. These studies recommend that to reduce airborne disease transmission in hospitals, safety and health measures are necessary. Such measures include the use of appropriate air conditioning systems, air ventilation, and personal protective equipment for staff [3].

Studies conducted by Abdollahi et al [4] on microbial air pollution in hospitals indicate that a very high percentage of hospital-acquired infections originate from wounds, surgical incisions, catheters, and surface contacts. Various bacteria and fungi play a significant role in causing infections and airborne contamination in hospitals. Ultimately, they have deemed the use of air purification and disinfection systems in hospitals and healthcare facilities necessary. Given the importance of health and safety in healthcare environments and the risk of disease transmission and spread among individuals, efforts have been made to identify high-risk areas for disease transmission and spread in healthcare facilities and to provide solutions to reduce disease spread and prevent the creation of high-risk environments.

One of the critical areas in healthcare facilities with high usage by individuals is the elevators. Considering the existing air pollution in hospitals, the lack of social distancing, and inadequate ventilation in the confined space of elevators, the spread of diseases among patients and those under treatment in this area has significantly increased. The various methods of disease transmission will be discussed further.

Methodology of Airborne Transmission of Diseases

Airborne transmission of diseases occurs in two ways: through dust and through droplet nuclei containing microorganisms.

Dust

Dust containing viruses, due to its prolonged presence in the air, moves through various sections as a source of contamination along with the air and can lead to the spread of infections in the environment, especially in hospitals. Additionally, dust formed from dried sputum combines with infectious secretions in the air, contributing to the contamination of hospital air. Therefore, to prevent the spread of infections through the air, appropriate ventilation systems in hospitals are necessary [5].

Transmission through Droplet Nuclei

One method of disease transmission between individuals is through sneezing. Each sneeze produces approximately 40,000 droplets ranging in size from 0.5 to 12 micrometers. The speed of these droplets can reach up to 100 meters per second during a sneeze. Some of these droplets settle due to gravity, while others remain suspended and move through the air. Coughing can produce up to 3,000 droplets [6].

Risk of Disease Transmission in Elevators and Confined Spaces

Studies conducted in this field indicate that proper ventilation in elevators can help reduce the likelihood of transmitting infectious diseases. Case studies regarding the health information of disease carriers and medical staff have shown that disease transmission is higher in elevators that are not properly ventilated. Therefore, adequate ventilation and the use of appropriate elevators can improve the sanitary conditions of hospitals and reduce the transmission of infectious diseases [7].

Other studies conducted on disease transmission in elevators show that proper ventilation can help reduce disease transmission through elevators. Air pressure, airflow, and ventilation rate in elevators have a significant impact on reducing disease transmission. Additionally, using appropriate air filters and correctly adjusting the ventilation can also be effective in reducing disease transmission [8]. According to the results obtained, these studies indicate that examining and improving ventilation in hospital elevators can play a crucial role in reducing the transmission of infectious diseases and improving the overall health of patients and medical staff. Therefore, it is recommended that designers and engineers of ventilation systems in hospitals fully adhere to the standards and technical guidelines related to ventilation systems. Additionally, periodic review and maintenance of ventilation systems are always necessary to minimize the spread of infectious agents in hospitals.

Considering the topic of disease transmission through the air, HVAC (Heating, Ventilation, and Air Conditioning) systems are among the most important systems that play a crucial role in preventing the spread of hospital-acquired infections through the air. Studies have shown that ventilation and air purification systems have a significant role in preventing the outbreak of viruses, such as the coronavirus [9]. Observations and studies conducted in some countries, including India, which are dealing with air pollution crises and microbial issues, indicate that ventilation and air dilution can contribute to the health and hygiene of individuals and help prevent an increase in mortality rates.

Air Conditioning and Air Purification

Air conditioning is a system whose main components include heating, cooling, and air exhaust systems. The four important factors controlled simultaneously in air conditioning systems are humidity, temperature, air speed, and air cleanliness. One of the goals of designing air conditioning systems in healthcare centers is air purification, creating a safe environment, providing overall comfort for the occupants, and preventing the spread of hospital-acquired infections. An air conditioning system comprises various parts such as air inlets and outlets, filters, processes (humidity control in summer, humidity removal in winter), heating and cooling equipment, fans, ducts, diffusers for proper air distribution, and exhaust for outgoing air [2].

Reduced performance and wear of air conditioning equipment, including filters, insulation, and poor maintenance in healthcare centers, lead to an increase in the spread of airborne diseases in hospitals due to the presence of airborne diseases [2]. In places where air, dust, and water are present, the number of microorganisms increases, making air conditioning systems an ideal environment for microbial proliferation [10]. Considering this issue, the proper design, maintenance, and monitoring of air conditioning systems, as well as air purification and in its advanced stage, air disinfection, ensure the provision of desirable air quality and prevent the growth and proliferation of hospital pathogens [10].

Principles of Operating Hospital Air Conditioning Systems

Air conditioning systems in healthcare facilities are designed based on the following objectives:

1. Maintaining air conditions at desirable temperature and humidity levels for patients, staff, and healthcare personnel.
2. Controlling odors.
3. Removing contaminated air.
4. Providing clean air to create a sanitary environment and protect staff from airborne pathogenic pathogens in the hospital.
5. Reducing the spread and transmission of pathogenic pathogens through the air between infected patients and other individuals [2,10].

Filtration System Design Requirements

To achieve desirable and high-quality indoor air, the first step is the physical removal of suspended particles from the air. Filtration is one of the most important methods of air purification. During air filtration, two sets of filters should be used in such a way that their efficiency ranges from 20 to 40 percent and greater than or equal to 90 percent, respectively, to remove suspended particles with a diameter of 1 to 5 microns. The second set of filters includes high-efficiency filters. This high-efficiency filtration system is used for sensitive areas such as intensive care units and operating rooms [11,12]. When high-efficiency air purification is needed in healthcare centers, the use of HEPA filters is necessary. According to the Centers for Disease Control and Prevention (CDC) in the United States and in accordance with the standards of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), these filters must be capable of capturing 99.97 percent of particles that are 0.3 microns or larger. They are used to prevent the spread of Mycobacterium tuberculosis and to limit the amount of airborne infectious pathogens [2].

Requirements for Designing Ventilation, Exhaust, and Air Movement Systems in Elevator Shafts

According to the safety engineering guidelines prevailing in the elevator industry, the following points should be adhered to:

1. The air in the shaft where the elevator is located, and which is more than two floors high, must be directed to the outside either directly or through the machine room.
2. The air exhaust vent from the elevator shaft should not be less than 1 percent of the cross-sectional area of the elevator shaft.
3. If the elevator cabin moves at a speed greater than 2.5 meters per second, the air exhaust area must be at least 0.3 square meters.
4. If there are two or three elevators in a shared shaft, an air exhaust vent of 0.3 square meters is sufficient. However, if the number of elevators in a shared shaft reaches four, the air exhaust vent must be increased to 0.4 square meters.
5. It should be ensured that the elevator shaft is protected in such a way as to prevent the entry of rain and snow, as well as birds and other animals.
6. The air exhaust should be operable manually.
7. The elevator shaft should not be used as a space for exhausting air from the building.
8. The air exhaust for the shafts of each group of elevators should be separate, with no shared exhaust between them [13].

Table 1. Types of Hospital Elevators and Their Safety Requirements [13]

Types	Dimensions	Safety Requirements
Elevators that can carry wheelchairs	-The minimum dimensions of the cabin are 1400 x 1100 mm -The minimum opening width in the cabin is 800 mm	-Be equipped with a re-leveling system. -Be equipped with a button to stay open in the cabin for a longer time than the normal door closing time.
Stretcher elevator	-The minimum dimensions of the cabin are 2100 x 1100 mm -The minimum opening width in the cabin is 900 mm	- Be equipped with a re-leveling system. -Be equipped with a button to stay open in the cabin for a longer time than the normal door closing time.

Bed elevator	-The minimum dimensions of the cabin are 2400x1400 mm -The minimum width and height of the opening in the cabin are 1300 and 2100 mm, respectively	-Be equipped with a variable frequency and voltage speed control system. -Be equipped with a re-leveling system. -Be equipped with a button to stay open in the cabin for a longer time than the normal door closing time. -Be equipped with a special key to provide the elevator to trained users. -Be equipped with an emergency power system so that the elevator is directed to the nearest floor when the power goes out.

Design Fundamentals of Ventilation, Disinfection, and Air Purification Systems in Hospital Elevators

Given the significance of hygiene in the confined space of hospital elevators, which serve as hubs for the dissemination and transmission of various diseases among individuals, it is imperative to design ventilation, disinfection, and air purification systems to enhance the safety and health of individuals in these environments. In the following, explanations regarding the designed system, the stages of ventilation, disinfection, and air purification in this system, as well as the placement and operation of this system in hospital elevators, are presented. It should be noted that due to the environmental conditions in hospital elevators and the presence of a very high microbial load, the design of ventilation and air purification systems, coupled with air disinfection and combating microorganisms in the air using UVC lamps, will be crucial in preventing the spread of airborne diseases. It is important to note that, based on the conducted investigations, a system for air purification, along with disinfection and combating bacteria and pollutants present in the air of hospital elevators, has not been introduced in Iran so far, and some prominent foreign companies such as Gree have managed to design products that only provide ideal temperature conditions in elevators.

It should be noted that the designed system, the subject of this article, differs significantly from Gree's product, and its functionality is based on air purification and disinfection (Figure 1).

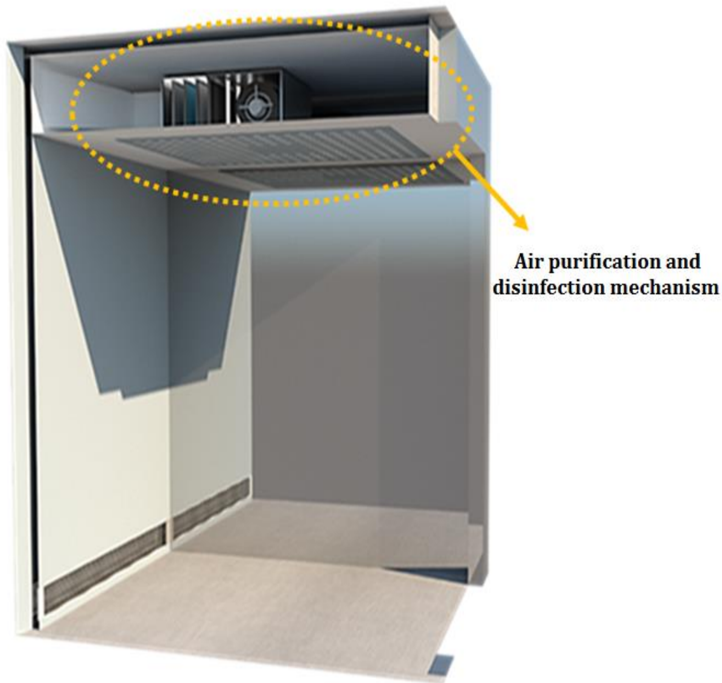

Figure 1. View of the air purification and disinfection mechanism installed in the elevator cabin

This system is designed with consideration of the operation of ultra-hygienic air handling units used in operating rooms. Given the different usage of elevators and their lower sensitivity compared to operating rooms, modifications have been made to this system, including the removal of heating and cooling systems. In this context, an air shower mechanism has also been utilized. By applying pressure to the air, this process removes suspended particles and various pollutants such as dust, bacteria, viruses, chemicals, and other possible contaminants that may be attached to individuals' bodies or clothing. This process is schematically illustrated in (Figure 2).

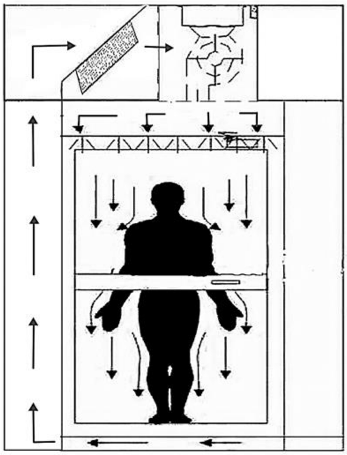

Figure 2. **Schematic representation of the designed system and the circulation of laminar airflow in the cabin (air entry from the ceiling)**

The operation of the aforementioned system is as follows: purified and disinfected air exits from the system designed and installed in the ceiling of the elevator cabin and enters the diffuser. The blown air stream moves from top to bottom in the form of an air shower. After providing the necessary fresh, purified, and disinfected air for the individuals inside the cabin, the air moves downward, capturing any potential pollutants along the way. At the bottom of the cabin, it is directed towards a vent designed to return the contaminated air to the device for re-purification (Figure 3).

Figure 3. **Illustration of the air circulation, purification, and disinfection process in the elevator cabin.**

This approach can be highly effective in reducing and eliminating air pollution inside the elevator cabin, thereby preventing individuals within the cabin from being exposed to pollutants and pathogens, and preventing the spread of contaminants and hazardous agents into sensitive areas. Therefore, in the design of the system discussed in this article, special effort and focus have been dedicated to achieving and introducing a suitable system for air purification and disinfection in the confined space of elevators in healthcare facilities.

Results and discussion

Considering the points mentioned, reducing the possibility of risks and problems that may arise due to the transmission of pathogenic agents is a necessity. For this purpose, according to the specific and interdisciplinary technical and operational conditions between mechanical engineering, elevator engineering and environmental health engineering, necessary action should be taken. This action can be very effective in order to reduce and eliminate the air pollution inside the elevator cabin and prevent the people inside the cabin from being exposed to pollution and pathogenic agents and the spread of pollutants and dangerous agents into sensitive spaces.

Therefore, in designing the system of this article, a special effort and focus has been made to obtain and introduce a suitable system for purifying and disinfecting the air in the closed space of the elevators of medical facilities. So, achieving this goal, can be defined and implemented in the form of the following stages.

Stage One

In order to design the dimensions and components of the air purification and disinfection system suitable for the required air volume for displacement and purification, in the first filtration stage, a metal filter with dimensions of 5×30×60 cm is used. This initial stage aims to separate large dust particles from the air. Metal filters, also known as washable filters, are typically employed in the first stage of air filtration. Considering the mesh size of the last perforated plate, these filters can capture suspended particles in the air with a diameter of approximately 1 millimeter and larger (Figure 4).

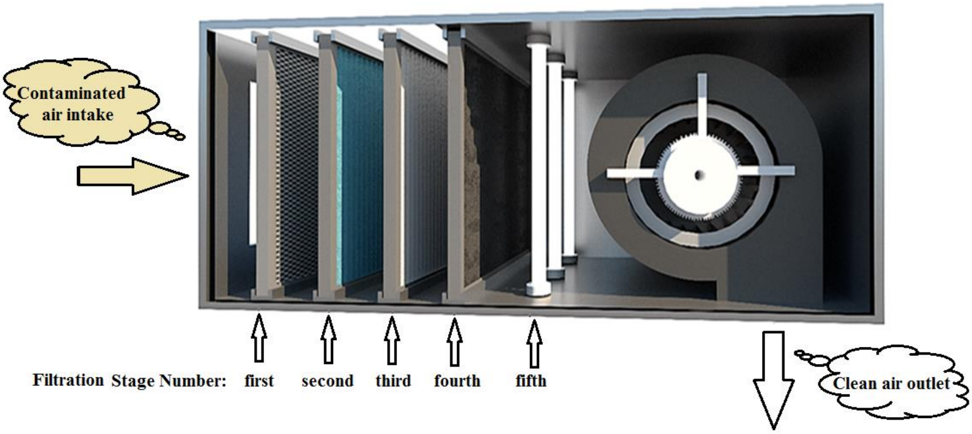

Figure 4. **A view of the filtration stages of the designed device**

Stage Two

In the second filtration stage, a pleated panel filter is used. Pleated filters are commonly made from polyester fibers. Other types of these filters can be made from polypropylene, polyurethane, and metal. This filter serves as a pre-filter for high-efficiency filters (HEPA filters), and the filter used in this section has dimensions of 5×30×60 cm (Figure 4).

Stage Three

In the third stage of the air purification and disinfection process, as shown in Figure 4, a high-efficiency particulate air (HEPA) filter is used. This filter has dimensions of 5×30×60 cm. It has the ability to capture particles with up to 99.5% efficiency and is classified as H12. This filter can capture particles such as fine dust, molds, pollens, bacteria, and viruses.

Stage Four

In the fourth stage of the air disinfection and purification cycle, as shown in Figure 4, an activated carbon filter with dimensions of 5×30×60 cm is used. Activated carbon filters are generally used for gases present in the air and for absorbing unpleasant odors and chemicals. Considering the conditions present in hospital environments, the use of this filter is essential to ensure comfort.

Stage Five

In the fifth stage of the ventilation, purification, and air disinfection process, as shown in Figure 4, UVC lamps (ultraviolet) are used. These lamps, by producing ultraviolet rays, have the ability to eliminate viruses and microbes. UVC lamps are used for disinfection and food packaging. UVC radiation disrupts the DNA of bacteria and microorganisms and is used for microbial decontamination in laboratories and hospitals (Figure 4). Studies on the impact of UVC radiation on microorganisms indicate that disinfection using UVC radiation significantly reduces the number of bacteria both directly and indirectly exposed to UVC radiation. Consequently, it can protect the next patient placed in the room. While UVC radiation might not be used alone, it serves as an excellent adjunct for disinfection [14,15]. In this regard, Figure 2 schematically illustrates the overall process of ventilation and air disinfection under laminar airflow conditions in the elevator cabin.

Conclusion

Since elevators in medical facilities are high-traffic environments and considering the microbial load present in them, the likelihood of disease transmission in these spaces is very high. Therefore, designing an air purification and particularly disinfection system in these spaces significantly helps to break the chain of contagious disease transmission and prevent the spread of diseases among individuals and within the community. This system can be used as a supplementary option for elevators in medical facilities and any place where controlling microbial load is important. Regulatory authorities can certify these elevators as equipped with an air purification and disinfection system by attaching appropriate notices or special approval labels. This can provide peace of mind to individuals when using such equipment. Therefore, considering the aforementioned points, this combined system with air disinfection capability in the elevator cabin can be a novel and innovative approach to preventing the spread of diseases. It not only offers high efficiency but also plays a crucial role in enhancing the effectiveness of the country's health and hygiene system, particularly in terms of controlling and preventing the spread of contagious infectious diseases.

Disclosure statement and funding

The authors declare no potential conflicts of interest. The present study received no financial support from any organization or institution.

Acknowledgment

The authors would like to give special thanks to all followers of this article, as well as the interested in the presented topic.

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