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Mini Review

The Role of Engineering Design in the Infection Control for Hospitals

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Abstract

Hospital buildings are designed with intrinsic features for infection control, and are related to an intensive energy use. The infection control program is structured in a hierarchy of administrative, engineering and PPE controls. Building design plays a major role, because it must not only incorporate the systems that are responsible for infection's engineering controls, but also the features demanded by the administrative controls. Basic understanding of the infection control hierarchy and strategies and stringent communication with the HICC in the design phase is necessary, not only to provide a healthy and safe environment, but to achieve rational solutions that minimize the complexity, operational and maintenance costs. This review paper contributes with basic information about these topics, and presents references for detailed and advanced information.

Keywords: Infection control; Hospital; Healthcare; Engineering design; Ventilation

Abbreviations: ACH: Air Changes Per Hour; ASHRAE: American Society of Heating, Refrigerating and Air-Conditioning Engineers; CDC: Centers for Disease Control; DHHS: U.S. Department of Health and Human Services; HEPA: High Efficiency Particulate Air; HICC: Hospital's Infection Control Committee; HVAC: Heating, Ventilation and Air-Conditioning; MERV: Minimum Efficiency Reporting Value; PPE: Personal Protective Equipment; UVGI: Ultraviolet Germicidal Irradiation; WHO: World Health Organization

Introduction

Hospital buildings are designed with intrinsic features for infection control, which contribute to produce an intensive energy use and significant greenhouse gas emissions [1]. The scope of this review paper is to provide basic information on these intrinsic features, and relevant reference for advanced information.

The Infection control program

In order for an infection to occur, it is necessary the presence of the infectious agent and its source, the mode of transmission, and a susceptible host, in what is called the "infection chain" [2]. The bacterial agents are one of the most common pathogens related to hospital-acquired-infections (nosocomial infections) in the United States [3], but fungal and viral agents are also reported [3]. One of the main sources of these agents, in the hospital application, are the diseased patients. In this case, those pathogens use body fluid secretions, blood, feces and droplets expelled by the respiratory track, among others, as a portal of exit. The expelled droplets are produced in a broad range of sizes during the respiration, talking, coughing and sneezing processes [4]. The larger droplets (order ≥100 μm) settle down within a small distance from the source (1 to 2m), due to the gravitational action. The smaller ones (order < 100 μm) may reach sizes that allow them to be suspended for a long time. References [5] and [6] provide detailed information about droplets dynamics in indoor environmental air.

The modes of transmission include direct contact during patient manipulation, indirect contact with contaminated surfaces (fomites) and airborne propagation (also a mode of indirect contact) [2]. Infection by the larger droplets is generally treated as direct contact [2]. Airborne propagation is related to droplet nuclei (size order ≤10μm) [7,8]. Reference [9] provides detailed information about airborne disease transmission.

The infection control program uses administrative, engineering and personal protective control measures [10], in the components of the "infection chain", in order to reduce the infection risk. Administrative controls are based on the stringent application of protocols. These require, among others, that universal precautions (hand hygiene, gloves when touching blood and secretions, etc.), must be used on all patient's manipulation, for instance. Surface disinfection and patient care products sterilization is another administrative control, among others. References [11] and [12] provide detailed information about the infection control program.

Engineering design and infection control

Building design must not only incorporate the systems that are responsible for infection's engineering controls, but also the features demanded by the administrative controls. The design team must keep in mind that engineering controls will not overcome the lacks in administrative controls, but these can promote protocols that can simplify the engineering design. Communication is a key factor for improving the engineering design.

Space design: Layout design must be planned in stringent relationship with the hospital's infection control committee (HICC), geared to provide adequate patient, staff, materials and waste flows, in order to prevent cross contamination. Basic knowledge on droplet dynamics may be used to understand the infection control criteria that are used to size the gap between patient beds, geared to reduce the risk of cross infection by droplet direct contact. For the case of airborne transmission, the infection control program generally demands that patients with airborne communicable diseases (e.g. tuberculosis, measles, etc.) must be isolated in an airborne infection isolation room (AII) [11]. A Protective Environment room (PE) is generally demanded for the isolation of immunocompromised patients (e.g. bone marrow transplant, oncology, etc.) [11]. Basic knowledge on transmission modes may be used to understand the criteria that is used to request smooth and cleanable finishing for walls and floors, geared to meet the sanitization demands that reduce the risk of cross infection by indirect contact.

Ventilation for dilution control: Although dilution ventilation is a key factor in healthy indoor environments, the design team must be aware that the strategy of increasing ventilation rates, in mixing ventilation mode, has limited effectiveness on airborne infection control [13-16]. Moreover, using high ventilation rates, in air-conditioned spaces, increase energy consumption and may disturb humidity control in hot & humid climates, leading to undesirable mold growth and amplification [17]. Memarzadeh [9] provides an excellent literature review on the role of ventilation on airborne infection control. The reader shall address references [18] and [19] for design guidelines of HVAC systems for hospital applications. Examination of all these studies [13-16] and references [9,18,19] show that maximum rational ventilation rates for dilution control in mechanical ventilated spaces are in the order of 10 ACH. Administrative controls, like source isolation or elimination are more effective than the use of increased ventilation rates, for the prevention of airborne communicable diseases in the hospital setting. The isolation of a source patient in an AII room (single bed) is an example of an administrative control. Staff training for prompt triage of undiagnosed or unsuspected patients with symptoms suggestive of an airborne communicable disease in patient's waiting area is another example. Those patients may be asked to use a surgical mask and instructed to observe strict respiratory hygiene and cough etiquette procedures, while in general public area. Reference [20] provides additional information on administrative control measures for airborne communicable diseases. The WHO [21] provides a guide on natural ventilation for infection control in health-care settings, and this strategy may be an attractive solution for many design locations, notably the low-income developing countries. Reference [10] provides additional information on strategies for reducing healthcare building´s energy use, while maintaining or improving effective airborne infection control.

Air filtering and disinfection: Guidelines demand the application of air filters in air-conditioned hospital settings [18,19]. These guidelines recommend that MERV-7 filters (efficiency > 90%, arrestance test) is the minimum filter requirement for coarse particulate control in any HVAC hospital application [18,22]. The requirement of additional filter banks, with higher efficiency for the fine mode particulate control, depends on the application, and is recommended for several ones, in the hospital setting [18,19]. ASHRAE recommends that MERV-15 filters shall be used in all area for inpatient care [18]. This recommendation needs to be analysed by the infection control point of view because of this filter's high efficiency against the droplet nuclei size order and fine particles size order (size particle most likely to be deposited deep in the lung). Besides that, HEPA filters are often required for some applications, as AII and PE rooms, orthopedic and transplant surgery [18], among others. References [22] and [23] provide detailed information about air contaminants, particulate control and air filter ratings and testing. In the absence of local code requirements, references [18] and [19] provide guidelines on filter selection for air-conditioned hospital applications. However, the room particle concentration decay due to the filtering technique obeys the dilution equation. In this case, the precedent section discussion applies, about the limited efficiency of dilution on infection control. Moreover, the design team must be aware that the application of high-efficiency filters increases the energy use, due to enhanced fan power to overcome the higher pressure loss. In that case, refer to reference [24], for special design considerations that may reduce pressure drop, and provide a rational solution.

An attractive air disinfection technology for airborne infection control is the use of upper-room UVGI (ultraviolet germicidal irradiation) fixtures. This technique relies on the germicidal action of UV in the wavelength range of 200-270 nanometers [18]. The lamp fixture is designed to irradiate the upper-room (unoccupied) zone, while preventing direct irradiation of the occupied zone. An additional room air mixing system (natural or mechanical) is demanded to provide the transport of airborne particles from the occupied to the irradiation zone. References [25-28] provide studies and results on this technique, and references [29-31] provide detailed information on guidelines for installation.

Conclusion

Engineering design plays a major role in the infection control for hospitals. Besides providing the engineering controls, the hospital design must meet the requirements of administrative controls. Basic understanding of the infection control hierarchy and strategies and stringent communication with the HICC in the design phase is necessary, not only to provide a healthy and safe environment, but also to achieve rational solutions that minimize the complexity, operational and maintenance costs.

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