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Estimating the germicidal effect of upper-room UVGI system on exhaled air of patients based on ventilation efficiency

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ABSTRACT

Upper room (UR)-ultraviolet germicidal (UVGI) systems, one of several disinfection applications of UV, target airborne infectious diseases in rooms of buildings such as healthcare facilities. Previous studies have introduced many experiments showing the germicidal effect of UR-UVGI systems. In this study, a novel numerical method of estimating the germicidal effect of UR-UVGI systems for air exhaled by ward patients was introduced. The method adopts and modifies the concept of ventilation efficiency because the germicidal effect depends upon how the air containing airborne infectious particles flows and stays within UV-radiated area. A case study based on a four-patient ward showed that UV doses were correlated with the age of the air exhaled by a source patient, as expected. Moreover, the UV doses were considerably affected by the position of the UR-UVGI system. Inactivation rates of the influenza virus estimated using the UV doses, were in the range of 48–74%, and those of Mycobacterium tuberculosis were 68–90% in the breathing area of a neighboring patient. The results indicate not directly the decreased concentration of airborne infectious particles, but the possibility of inactivation caused by the UR-UVGI system, which is useful for system optimization.

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1. Introduction

The ongoing likelihood of a global influenza epidemic and the threat of bioterrorism require more sophisticated building hygiene systems to prevent their spread during the initial stage. As one of the countermeasures against these threat, ultraviolet germicidal irradiation (UVGI) systems have attracted attention. The use of UV radiation for germicidal purposes has a long history, but its practical application was only considered after the identification of UV radiation emission from discharge lamps in the early 20th century [1]. A number of infectious microorganisms and viruses that have been prevalent at the time, such as influenza and tuberculosis, were shown to be effectively inactivated by UV radiation [2,3]. For example, Wells had performed several initial experiments showing the germicidal effect of UV radiation in combating airborne infectious microorganisms as done by other researchers [4] [5]. His book, published in 1954, was one of the first comprehensive sources that described the characteristics of airborne infectious diseases and the effective usage of UV radiation [6].

UVGI systems used to disinfect indoor air are mainly divided into two types, upper room (UR)-UVGI and in-duct (ID)-UVGI systems [7]. A ID-UVGI system can be an effective countermeasure when infectious microorganisms pass through air conditioning units or ducts during the contagion stage. On the other hand, a UR-UVGI system installed in a room begins to inactivate infectious airborne microorganisms, as soon as they are emitted from one or more sources and exposed to UV rays in the room, due to proximity. This inactivation can prevent the dispersion of airborne microorganisms not only in the room but also to other rooms. The position of the UR-UVGI systems is restricted to locations safe for occupants, such as the upper part of the room, and several horizontal louvers are usually placed in front of UVC lamps to ensure horizontal UVC rays only radiate the upper part of the room, because UVGI systems use the ultraviolet C-band (UVC) with wavelengths in the range 200–280 nm. This wavelength range has a germicidal effect on a wide range of microorganisms, but is also known to possibly cause skin redness and eye irritation when overexposed to humans [8]. Therefore, it is important to identify factors such as the airflow transferring air from the lower space to the upper space and the distribution of UVC intensity from the UR-UVGI system. Experimental methods using less harmful microorganisms in full-scale chambers have been employed to evaluate the germicidal efficacy of UR-UVGI [9–11], but it is costly and slow to evaluate and design UR-UVGI systems using experimental methods at the design stage. Therefore, numerical methods have been applied by several studies [12,13].

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